# PRODUCT ENGINEERING

JUNE 1946

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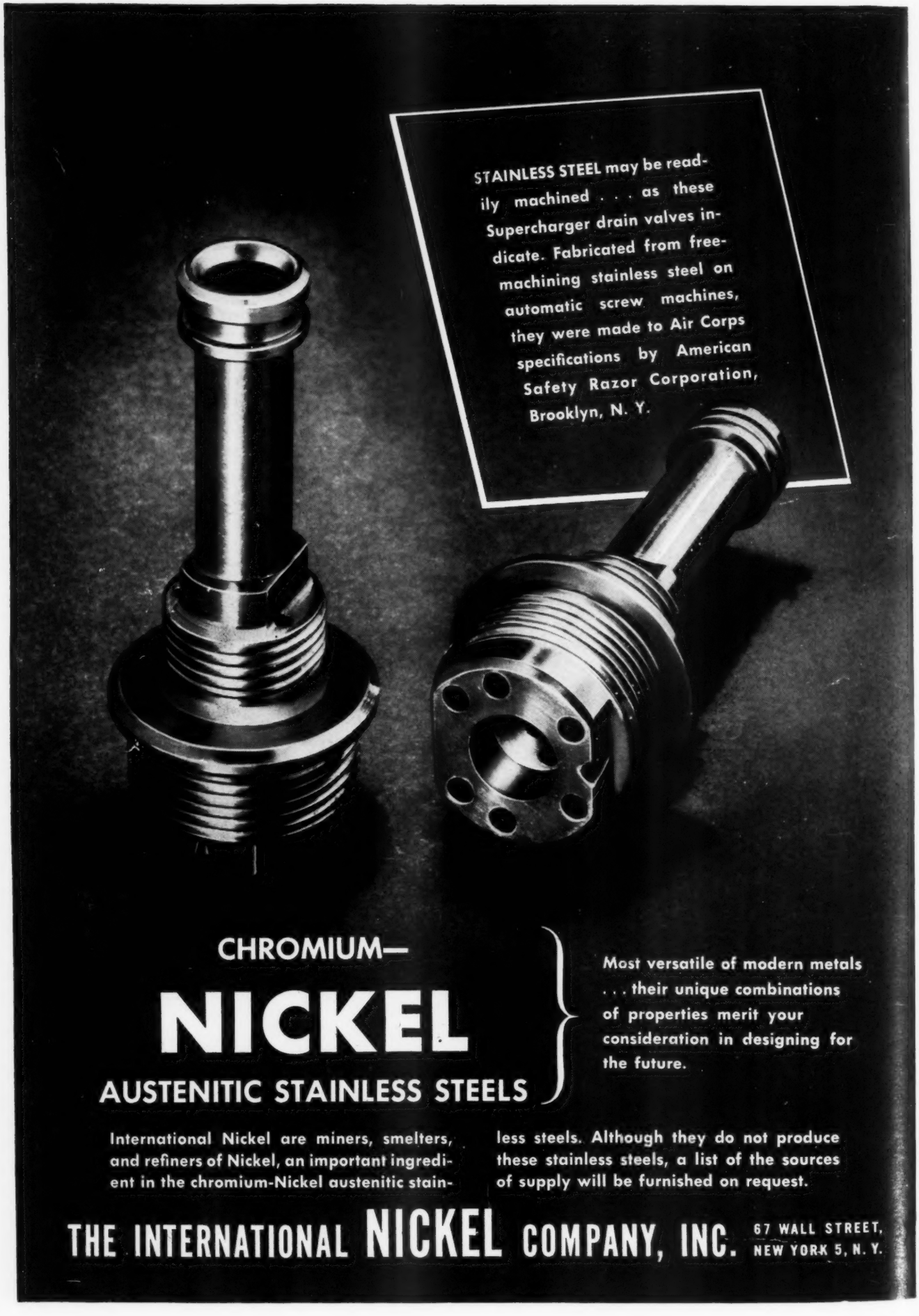
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PRODUCT ENGINEERING

JUNE, 1946

# PLASTER MOCK-UPS

## Reduce Engineering Problems

## In Bus Body Design

**CLIFFORD SMITH**
Design Engineer, ACF-Brill Motors Company

BUS BODIES were once box-like structures and did not have double curvature surfaces. It was relatively simple to visualize the appearance of these designs and to produce the necessary layout drawings, because most of the surfaces were flat perspective drawings and artist's renderings conveyed to the sales department and the prospective customer an exact picture of the proposed design. Also, it was comparatively easy for the production department to visualize the manufacturing problems by merely studying the arrangement and detail drawings.

When the demand for modern styling, with its rounded corners and double curvatures, made it necessary to develop such designs at reasonable cost, the engineering department was faced with a number of vexing problems. To layout all of the double curvatures and then attempt the production of an artist's rendering from the basic design drawings, was not only time consuming and costly, but it was also difficult for the sales force and the prospective customer to visualize what the finished product would look like from all angles. Usually, further modifications in the design were demanded thereby necessitating additional engineering design. It was also extremely unsatisfactory for the production department to attempt to make manufacturing cost estimates from the design layout. Finally, the number of units per bus order is usually comparatively small, rarely exceeding one hundred. Hence, engineering costs must be kept relatively low.

Under the new method of developing the design from plaster mock-ups, the ACF-Brill Motor Company is not constrained by the limitations imposed by the older and more conservative method that formerly was followed in the design of a bus body. With this new system, much of the time that was formerly spent in the design, engineering, and make-up of complicated layouts and drawings has been eliminated. The production department was formerly required to make the necessary tools and fabricated parts to produce a pilot model to submit to company executives for inspection and criticism. Design and manufacturing executives were therefore unable to pass judgment on the design until much time and money had been spent for engineering drawings, tooling, and other pilot model costs. If design changes for better appearance or simplicity of manufacturing were required, a considerable loss of time and money resulted, because of the necessary redesigning and retooling.

As an example of the use of plaster mock-ups and the manner in which they reduce engineering and tooling expense, consider the front end of a typical city transit coach. The design of this portion of the coach is primarily a problem in surface development, wherein the best form, both esthetically and functionally, is desired. In using the plaster mock-up technique, the primary basic lines are plotted by the designer. With these basic lines as the starting point, the mock-up is then developed as a full-size model that can be viewed, criticized and modified without entailing any great expense. Because this mock-up is sculptured in plaster on a wood form that spcifies the basic contour lines, detailed double curvatures can readily be swept in as desired. Complex changes can be made simply by adding or chipping-off plaster and fairing the surfaces.

When the full-scale mock-up has been finally developed and approved, it is then used, as will be described, in the economical manufacture of the Kirksite dies. The mock-up can also be used to produce the layout drawings.

After the body designer has made a scale development of the body surfaces and investigated the practicability of the artist's conception with regard to the general proportions, structure, and legal requirements of the bus body, he develops the full-size basic contours. These contours are the profile at the center line, body lines, belt line, post shapes and station shapes with their line points and relations to the mock-up pedestal that is constructed of plywood, steel angles, and tubes. At this point, production on the plaster-mock-up is started. The designer gives the basic contours to the plaster

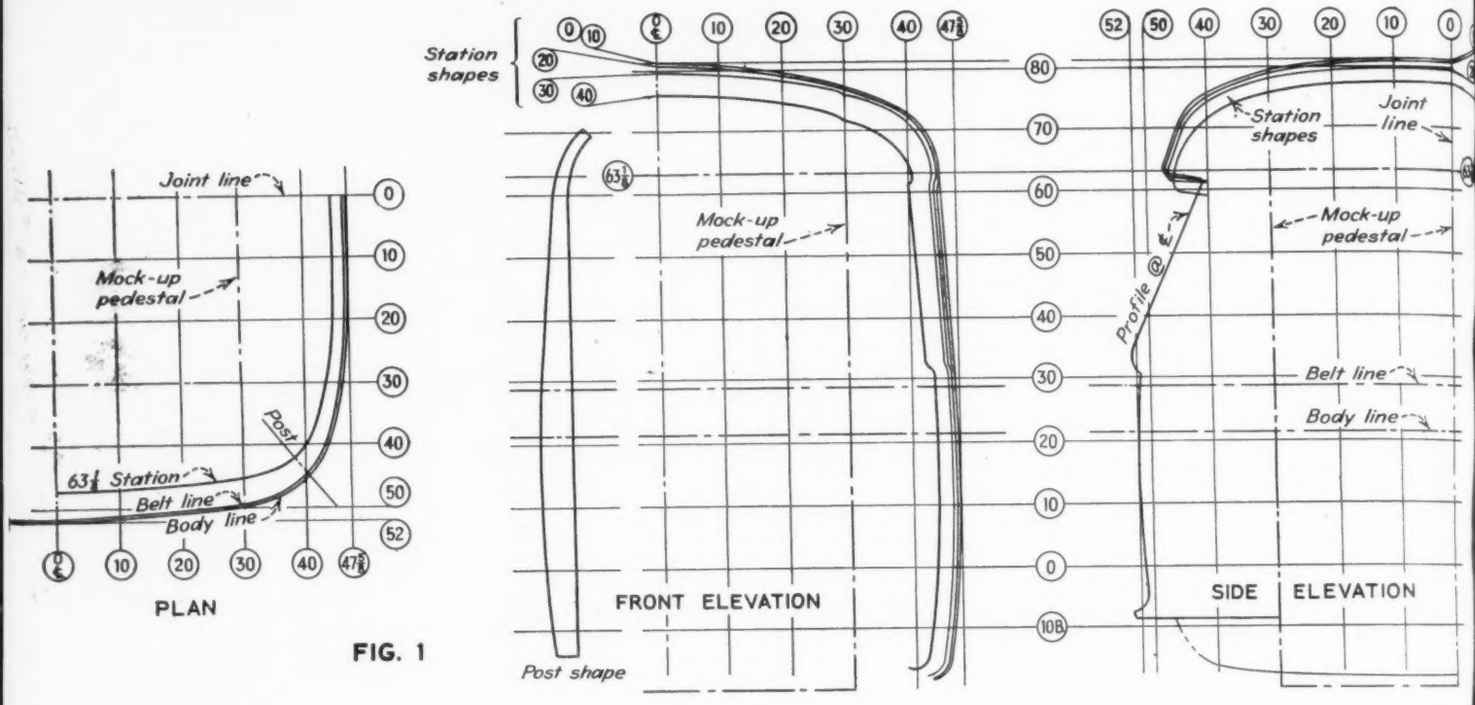



FIG. 1

Fig. 1—Development of basic profile contours at center line, body, and belt lines, and post and station shapes.

Fig. 2—Station lines on plywood mock-up pedestal.

Fig. 3—Longitudinal and transverse templates slotted, keyed and mounted at 10 in. stations on mock-up pedestal.

Fig. 4—Three-dimensional view of assembly with dimensions, sections, station points and fabrication data shown.

Fig. 5—Preliminary plaster model of bus marker light.

Fig. 6—Transition surface blended from plaster model of market light into homogenous mass of panel surface.

Fig. 7—Negative plaster station shape taken off mock-up.

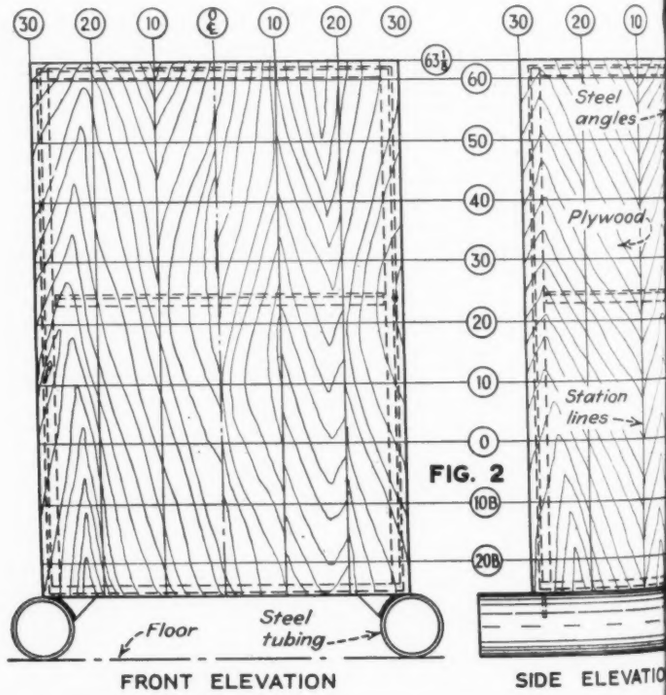
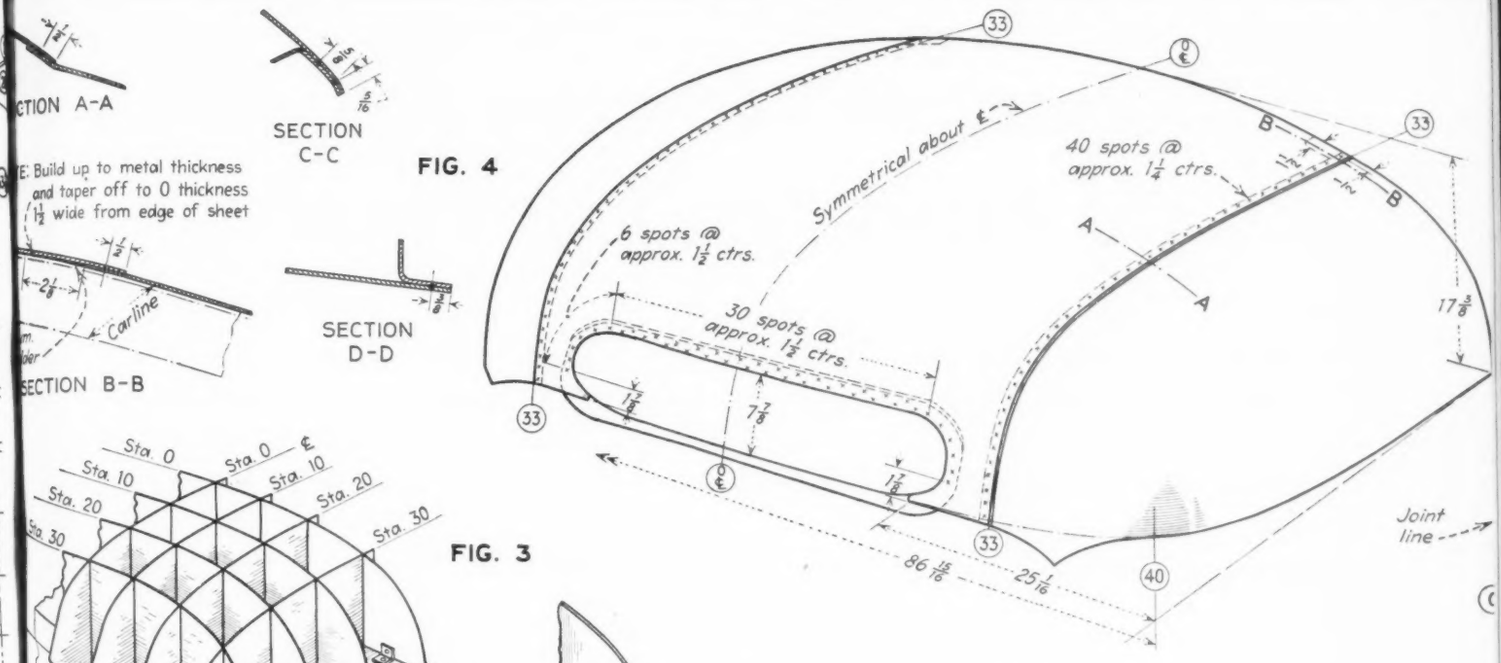


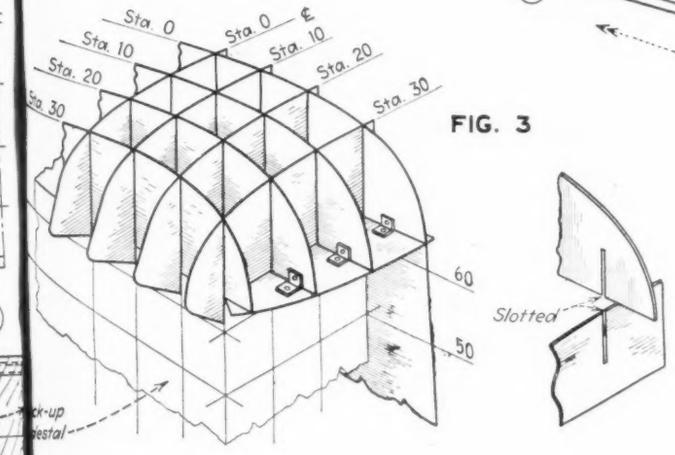

FIG. 2

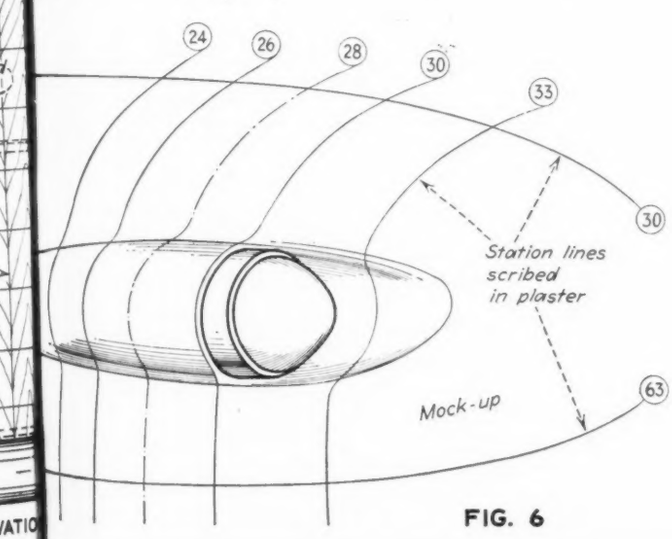
model maker who then cuts corresponding shapes out of sheet metal and scribes the station points on their surfaces. These metal shapes, or templates, are made to fit the mock-up pedestal. As shown in Fig. 2, the station lines are laid out on the plywood surfaces of the pedestal.

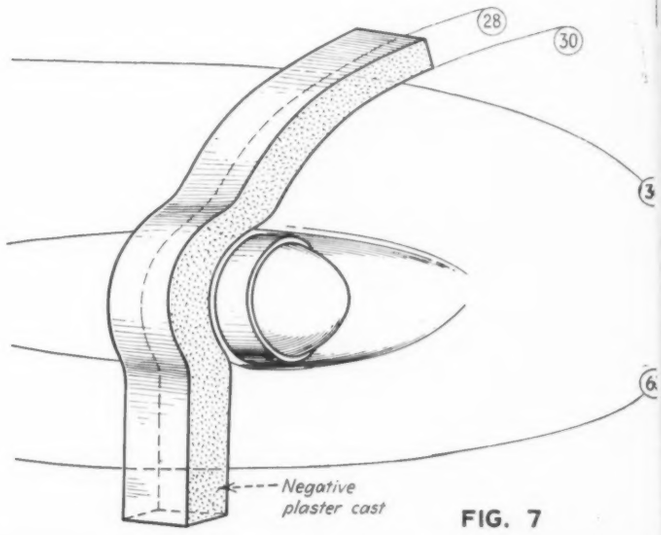
With the basic contour templates mounted on the mock-up pedestal, longitudinal and transverse templates are added at 10 in. stations. These longitudinal and transverse templates are slotted to permit a keying together in an egg crate fashion, as shown in Fig. 3. Perspective sketches are then prepared to show the area to be blended, determined, or faired-in. After all necessary templates have been attached to the pedestal, the spaces are filled in with rough plaster. A finish coat is then applied and the surface splined smooth to the contours established by the templates. The windshield and window opening areas are determined from a layout of true shape and angularity. Ornamentation, such as headlights, directional lights, bumper, belt and drip moldings, are simulated in plaster and applied to the mock-up to present a realistic appearance. On page 437 the finish mock-up and front end view of this typical transit coach is shown.

The engineered mock-up has many advantages. It minimizes the amount of engineering layout and drawing work and enables the designer to work out the blending and fairing of areas to get the most pleasing proportion. It eliminates large detail drawings of sheet metal and structural parts, as these are supplanted by a broad use of perspective detail in the assembly drawings. These drawings show the station relation points tying in with the engineering layout and the station templates of the mock-up and usually show one view with detail sections, overall dimensions and fabrication information. They require a fraction of the time required in making conventional three-view production drawings of panels, structures and assemblies. Lines can be scribed on the


SECTION A-A
SECTION C-C
E: Build up to metal thickness and taper off to 0 thickness 1½ wide from edge of sheet
Carline
SECTION B-B
SECTION D-D
FIG. 4
Symmetrical about ℄
40 spots @ approx. 1¼ ctrs.
6 spots @ approx. 1½ ctrs.
30 spots @ approx. 1½ ctrs.
Joint line
FIG. 3




plaster surface to determine sheet laps and conditions, cut lines and structural shapes with their locations.

The mock-up is a check on engineering layout before expensive tooling is started. Any production difficulties that may arise from the new design can be foreseen. It also permits determination of the most economical method of manufacturing, such as die sizes for pressed panels, shaping of structural members, and the tooling required.

The plaster mock-up makes possible creative engineering in surface design. Consider as an example, the blending of a marker light into the front hood panel surface to attain pleasing appearance and the best conditions for manufacturing. A plaster model of the light is first made. This is placed at a location determined by the designer and, through a transition surface, blended into the homogenous and unbroken mass of the panel surface.

Not only does such a creative design procedure achieve at minimum expense the acceptable form and shape desired, but it also reduces the cost of making the engineering layout drawings necessary in developing design details and required records. This is done by casting plaster negatives over the surface at the plaster station where the contour layout is desired. This cast plaster negative is placed in proper position at the proper station location on the layout and the designer simply traces the contour by running a pencil along the plaster cast. Fig. 7 illustrates a typical negative plaster station shape taken off the mock-up. The amount of engineering layout work is thus greatly reduced and the accompanying design problems are correspondingly simplified.

The approving authorities, the engineering and sales executives, can base their opinion, suggestions and approval upon the mock-up before production commences. The mock-up also greatly reduces the cost of making the Kirksite dies because these can be cast directly or indirectly against the surface of the plaster mock-up.

# Displacement Correction Factors For Rotary Spur Gear Pumps

**Influence of tooth clearance, tooth space volume, backlash and pressure angle on pump displacement are analyzed and evaluated. Values of correction factors, for use in a simple general displacement equation, are obtained from planimeter measurements of gear tooth profiles and compared with displacements of hand cranked pumps.**

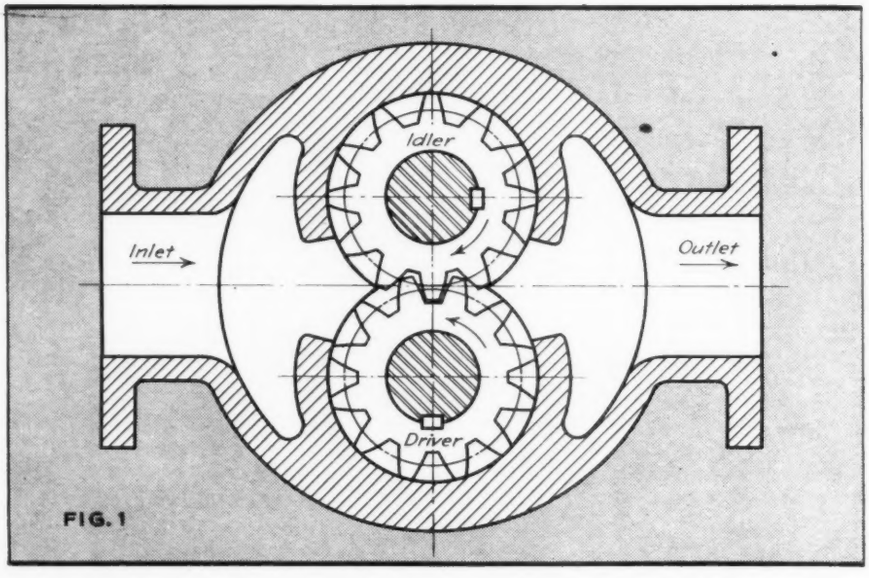



Fig. 1—Parts in a rotary spur gear pump and direction of fluid flow.

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Research Engineer,
Gulf Research & Development Company

MANY DISPLACEMENT FORMULAS or equations are commonly used in calculating the discharge volume of rotary spur gear pumps. Most of them are not accurate because they do not take into consideration the difference in the tooth clearance and tooth space volumes of the mating gears, nor the pressure angle of the involute profiles.

The volume of fluid discharged by each gear in a spur gear pump, Fig. 1, in one revolution is, theoretically, equal to the number of tooth spaces times the space volume between two consecutive teeth. But with the gear teeth in action, this theoretical displacement is decreased by the clearance volume trapped between every pair of mating teeth at the seal point as the driving tooth contacts its mate on the idler gear.

The initial seal position of the gears is shown in Fig. 2, in this position the cross-section of the clearance volume is the area *DFGHACD*. After sealing, the clearance volume decreases and reaches a minimum when the center of the area crosses the line connecting the gear centers. This position of minimum volume is shown in Fig. 3 and is represented by the area *DEFGHACD*. The decreasing clearance volume compresses the fluid trapped between the mating teeth unless it is squeezed out or is relieved by side porting as shown in Fig. 3 by the dash line.

In a properly designed spur gear pump this relief carries the excess fluid to the outlet side, and the fluid in the minimum clearance volume is returned to the inlet side. The volume trapped at the moment of sealing corresponds to the clearance volume in a piston pump between the piston face and head plus the port volume up to the valves. In the rotary pump this volume is carried back to the inlet side because the teeth do not fill the tooth spaces when fully meshed.

The clearance volume can be relieved also by placing a side port in the inlet side at the point of contact as the initial seal position is reached as shown by the dash line through G, Fig. 2. In this design, the maximum clearance volume is returned to the inlet side, thus reducing the displacement of the pump as compared to one having the relief port on the outlet side at the point of contact as the minimum clearance volume is reached. In a pump designed to return the maximum clearance volume to the inlet side, the displacement factor is reduced by a small percent for a six-tooth gear to about 7 percent for a twelve-tooth gear.

With the pitch diameter remaining constant, the magnitude of the tooth space volume *ABDCA*, Fig. 3, as outlined between the tooth contours and tooth tip circumference depends upon the pressure angle, backlash and number of teeth in the gear.

With a change of pressure angle, areas of standard full depth teeth of true involute form when measured with a planimeter indicate some difference in displacement. The greater the pressure angle is, the greater is the displacement.

The effect of pressure angle on clearance is shown in Fig. 4. The gear shown in solid outline has a pressure angle of 15 deg. The gear shown in dash line has a pressure angle of 28 deg. In changing from the 15 deg. to the 28 deg. pressure angle, twice the space area *ABCDA* is increased by four times area X and is decreased by four times the area Y; also the minimum clearance area is increased by twice area X and decreased by twice area Y. In addition, the clearance is decreased by twice the area Z. The net displacement area of the contour for the gear with 28 deg. pressure angle varies from that of the gear with the 15 deg. pressure angle by

$$2n(X - Y + Z)$$

Area X would probably more than balance

area **Y**, so that some part of area **Z** represents the change in displacement area.

A change in backlash increases or decreases both twice the space volume and minimum clearance an equal amount, so that the difference or net displacement volume, Fig. 3, remains the same, that is,

$$2x\ (ABDCA - DEFGHACD)$$

indicating that the net displacement volume is not affected by backlash.

The effect of backlash on displacement is indicated in Fig. 5 where the gear teeth are narrowed from the solid outlines to the dash outlines and then moved into contact. With backlash in the two adjacent tooth spaces, area *ABCDA* is increased by area 3 X and decreased by area X, while area *EFGHE* is increased by two times area X, making a net increase of four times area X. The total clearance area is increased by areas X and 3 X, balancing the change in the adjacent spaces. A small gain Y at one end of the trapped area is balanced by a loss at the other end. Hence the difference between twice the space area and clearance area is maintained and displacement is not affected.

Clearance at root of tooth occurs once in each space of both gears and twice in each clearance area and, therefore, cancels out any effect on the displacement.

The foregoing analysis, therefore, indicates that the general formula for calculating displacement in terms of the dimensions of the pump, where

$V$ = pump discharge, cu. in. per revolution
$a$ = addendum of gear teeth, in.
$D$ = pitch dia. of a gear, in.
$W$ = face width of gears, in.

$$V = 2\pi aDW \qquad (1)$$

should be used with a correction factor when accurate computations are required.

To obtain data from which to establish values of correction factors F, large scale sections were drawn for gears of 6 in. pitch diameter, having twelve, eight, and six teeth. This was done for gears having 28, 20 and 15 deg. pressure angles. The gears were laid out with involute profile, no backlash, and a standard addendum of 1/D.P. For each gear the tooth space area and minimum clearance area were measured by planimeter.

In laying out the tooth contours the six tooth gear was drawn 4 times size, the eight tooth gear $5\frac{1}{3}$ times size, and the twelve tooth gear 8 times size. This procedure made the tooth depth the same for each gear in measuring with a planimeter.

Multiplying the difference between the space area and the minimum clearance area by twice the number of teeth per gear gave the net displacement per inch of gear face for each pump.

Displacement correction factors **F** were then calculated for the group of gears by the equation

$F$ = displacement correction factor
$D_P$ = net displacement as determined by planimeter readings
$D_C$ = calculated displacement by Equation (1)

$$F = D_P/D_C \qquad (2)$$

The summary in Table I gives working data and the factors obtained for gear teeth of three different pressure angles with involute contours and no backlash. These data

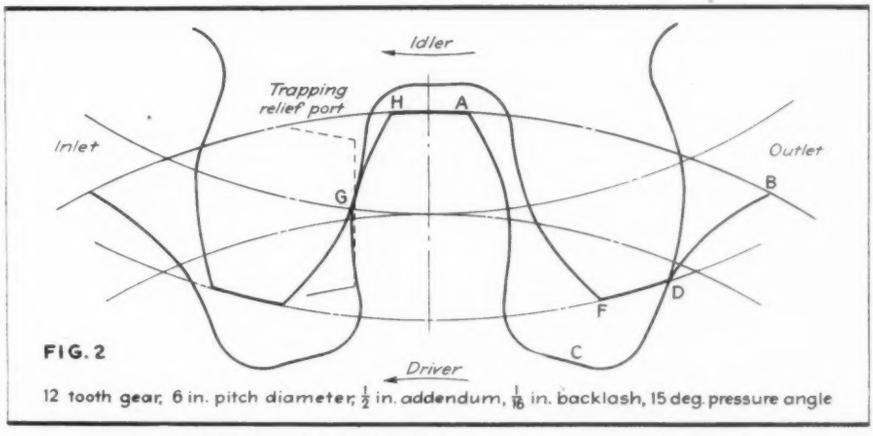


**Fig. 2—Initial seal position of pump gears occurs when tooth on driving gear comes in contact with tooth on idler gear.**

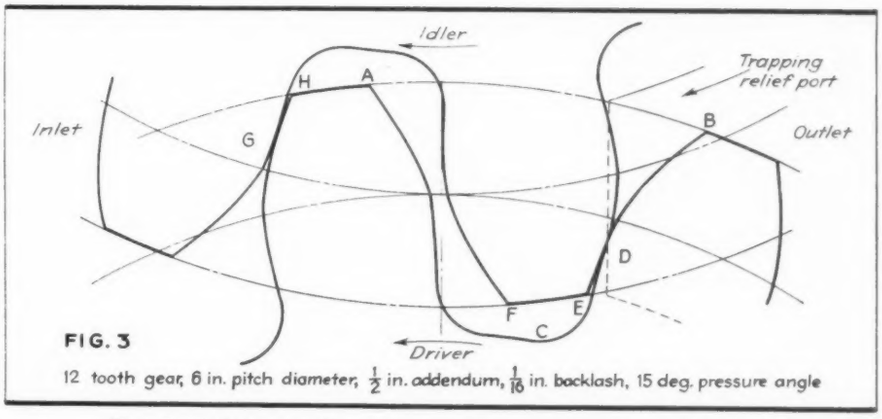


**Fig. 3—Minimum clearance position occurs when center of clearance volume crosses the line connecting the gear centers.**

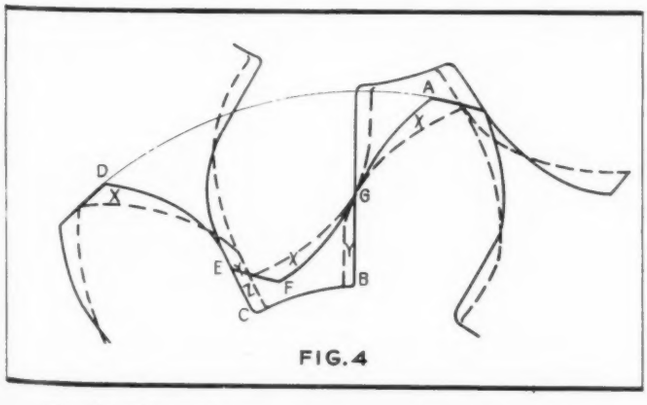


**Fig. 4—Effect of pressure angle on clearance volume.**

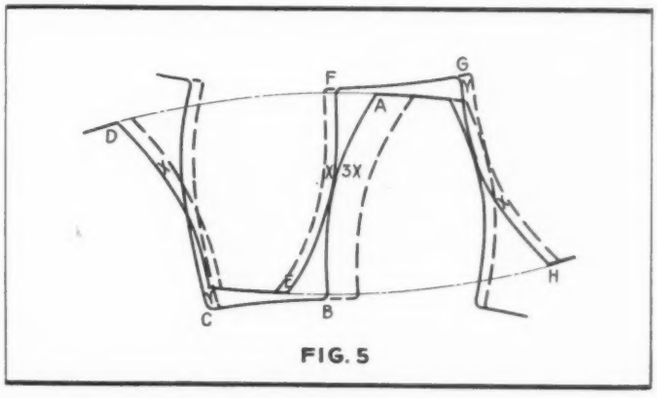


**Fig. 5—Effect of backlash on clearance volume.**

**Table I—Effect of Pressure Angle on Displacement Factor**

| Pressure angle, deg. | Teeth per gear | Pitch dia., in. | Addendum, in. | Face width, in. | $D_c$ Calculated displacement, cu. in. | Total space volume, cu. in. | Total clearance volume, cu. in. | $D_p$ Net displacement, cu. in. | Displacement factor, $D_p/D_c$ |
|---|---|---|---|---|---|---|---|---|---|
| 28 | 12 | 6 | 0.5 | 1 | 18.850 | 21.598 | 2.207 | 19.391 | 1.0287 |
| 20 | 12 | 6 | 0.5 | 1 | 18.850 | 22.067 | 2.792 | 19.275 | 1.0226 |
| 15 | 12 | 6 | 0.5 | 1 | 18.850 | 22.098 | 2.915 | 19.183 | 1.0177 |
| 28 | 8 | 6 | 0.75 | 1 | 28.274 | 33.881 | 4.315 | 29.566 | 1.0457 |
| 20 | 8 | 6 | 0.75 | 1 | 28.274 | 34.000 | 4.762 | 29.238 | 1.0341 |
| 15 | 8 | 6 | 0.75 | 1 | 28.274 | 33.879 | 4.787 | 29.092 | 1.0289 |
| 28 | 6 | 6 | 1.0 | 1 | 37.699 | 46.508 | 6.640 | 39.868 | 1.0575 |
| 20 | 6 | 6 | 1.0 | 1 | 37.699 | 46.406 | 7.103 | 39.303 | 1.0425 |
| 15 | 6 | 6 | 1.0 | 1 | 37.699 | 45.840 | 6.987 | 38.853 | 1.0306 |

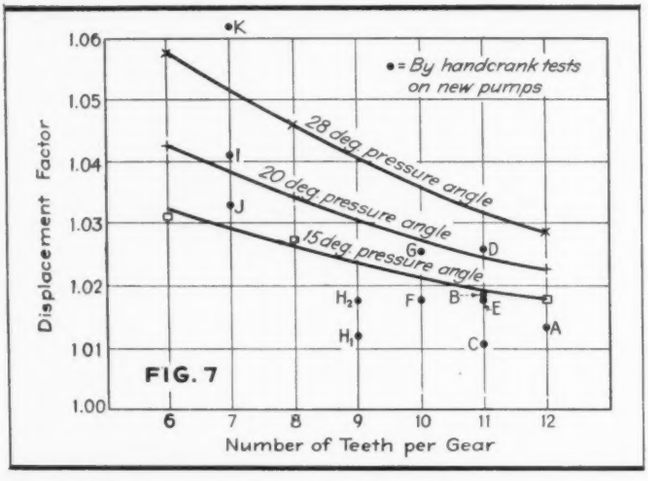
Displacement Factor
Number of Teeth per Gear
●= By handcrank tests on new pumps
28 deg. pressure angle
20 deg. pressure angle
15 deg. pressure angle
FIG. 7

Fig. 7—Displacement factors calculated from measurements for pumps with relief ports on the outlet side, using number of teeth per gear as a base.

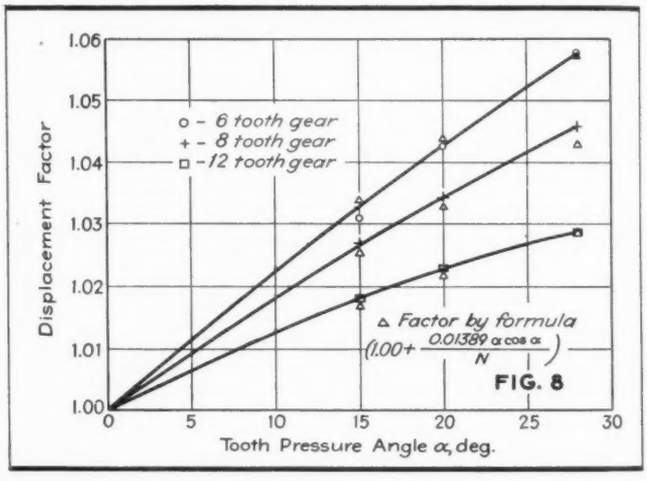


Fig. 8—Displacement factors calculated from measurements for pumps with relief ports on the outlet side, using tooth pressure angle as a base.

show that the correction factor increases as the number of teeth decreases, and that for the same number of teeth the correction factor decreases with the pressure angle.

Large scale sections were also drawn for gears of 6 in. pitch diameter having twelve and six teeth, with backlash equal to $\frac{1}{8}$ of the addendum. Tooth space area and minimum clearance area for these gears were measured by planimeter and displacement factors calculated by the same procedure used for gears without backlash. In Table II data for twelve and six tooth gears with backlash are compared with similar data for gears without backlash. Note that backlash has no effect on displacement.

In actual operation all the selected gears, except the eight and twelve tooth gears with 28 deg. pressure angle, encounter interference and require some contour modification. This interference can be eliminated either by allowing the standard tooth gear cutter to undercut the gear teeth or by modifying the standard involute tooth form.

If the teeth are undercut the change of contour will add a like amount to twice the space area and minimum clearance area so that the net displacement will remain the same. If the tooth form is modified, the resulting change of the space area and minimum clearance areas may not be the same, therefore, the true displacement can be determined only by laying out the contours to scale and measuring the two areas with a planimeter.

To check the correction factors obtained by measurement of tooth space and clearance space areas of the layouts, all the spur gear pumps in new condition at the laboratory were collected and their gears measured. Using a test setup as shown in Fig. 6, the discharge of each pump was determined by hand-cranking, with the inlet and outlet of the pump under constant and equal head.

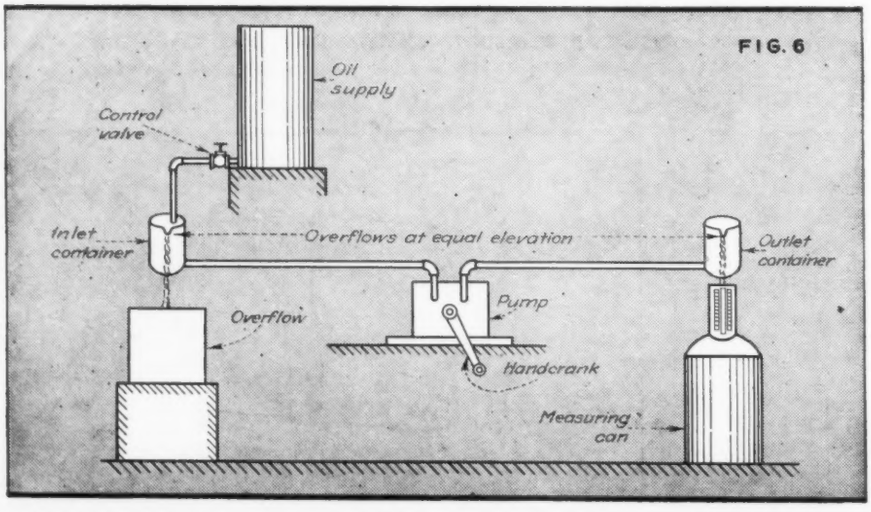


Fig. 6—Test setup for determining the displacement of pumps by hand cranking.

The quantity of liquid discharged divided by the number of crank revolutions required gave the displacement per revolution of the pump, this quantity was called the "hand-crank displacement."

A correction factor was computed for each pump by dividing the hand-crank displacement by the calculated displacement obtained from Equation (1). Table III gives these data for the pumps tested.

Correction factors obtained from hand-crank tests (Table III) and those obtained by measuring the gear profile drawings with a planimeter (Table I) are compared in Fig. 7 on the basis of number of teeth per gear. The smaller factors obtained for some of the hand cranked pumps may be attributable to the methods of relief porting. This was not investigated at the time of test.

Correction factors from Table I are plotted in Fig. 8 against tooth pressure angle for six, eight and twelve teeth gears.

An analysis of the curves in Fig. 8 shows that the correction factor $F$ is closely approximated by an equation in which

$F$ = correction factor
$N$ = number of teeth per gear
$\alpha$ = pressure angle of gear teeth, deg.

$$F = 1.00 + \frac{0.01389\ \alpha \cos \alpha}{N} \qquad (3)$$

Correction factors calculated from Equation (3) for 6, 8 and 12 teeth gears of 15, 20, and 28 deg. pressure angles are plotted on Fig. 8. The greatest deviation from the curves is not more than a fourth of one percent.

Combining Equation (1) with Equation (3) yields an equation that can be used to predict accurately the discharge V of spur gear pumps.

$$V = 2\pi a D W F$$

$$= 2\pi a D W \left(1.00 + \frac{0.01389\ \alpha \cos \alpha}{N}\right) \qquad (4)$$

The curves on Figs. 7 and 8 are to be used only for pumps designed with relief ports on the outlet side, as at $D$, Fig. 3. With the relief port in this position, the minimum clearance volume is returned to the inlet side.

Correction factors obtained from planimeter measurements of gear tooth profiles are plotted for number of teeth per gear in Fig. 9, and for tooth pressure angle in Fig. 10, for pumps in which the trapped volume at the initial seal position escapes through ports on the inlet side.

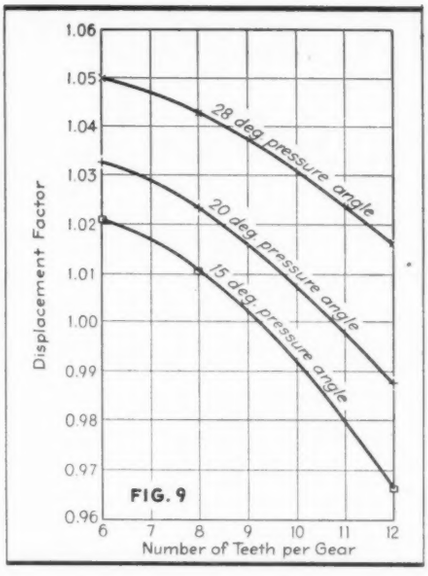


**Fig. 9 — Displacement factors calculated from measurements for pumps with relief ports on the inlet side, using number of teeth per gear as a base.**

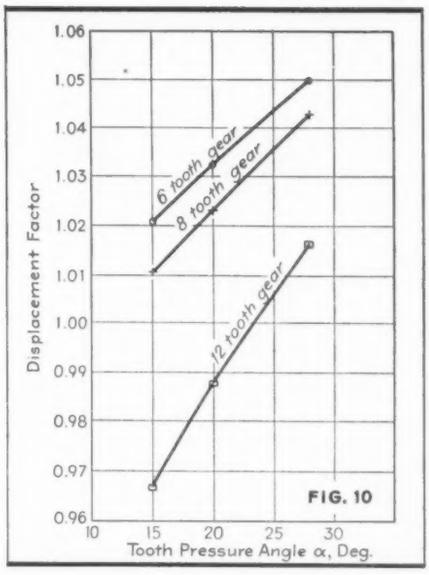


**Fig. 10 — Displacement factors calculated from measurements for pumps with relief ports on the inlet side, using tooth pressure angle as a base.**

**Table II—Comparison of Gears With and Without Backlash**

| Backlash | Teeth per gear | Pitch dia., in. | Addendum, in. | Face width, in. | $D_C$ Calculated displacement, cu. in. | Total space volume, cu. in. | Total clearance volume, cu. in. | $D_P$ Net displacement, cu. in. | Displacement factor, $D_P/D_C$ |
|---|---|---|---|---|---|---|---|---|---|
| None | 12 | 6 | 0.5 | 1 | 18.850 | 22.098 | 2.915 | 19.183 | 1.0177 |
| 1/8 add. | 12 | 6 | 0.5 | 1 | 18.850 | 22.848 | 3.665 | 19.183 | 1.0177 |
| None | 6 | 6 | 1.0 | 1 | 37.699 | 46.406 | 7.103 | 39.303 | 1.0425 |
| 1/8 add. | 6 | 6 | 1.0 | 1 | 37.699 | 47.812 | 8.508 | 39.304 | 1.0426 |

**Table III—Comparison of Calculated and Hand-Crank Displacements**

| Pump | Pressure angle, deg. | Teeth per gear | Addendum, in. | Pitch dia., in. | Face width, in. | $D_C$ calculated displacement, cu. in. | $D_H$ Hand-crank displacement, cu. in. | Displacement factor, $D_H/D_C$ |
|---|---|---|---|---|---|---|---|---|
| A | 24 | 12 | 0.1235 | 1.378 | 1.250 | 1.3361 | 1.3546 | 1.01346 |
| B | .. | 11 | 0.125 | 1.375 | 0.748 | 0.80778 | 0.8228 | 1.01859 |
| C | .. | 11 | 0.125 | 1.375 | 1.123 | 1.21275 | 1.2257 | 1.01068 |
| D | 28 | 11 | 0.14525 | 1.601 | 3.1268 | 4.56865 | 4.6870 | 1.02590 |
| E | 28 | 11 | 0.14525 | 1.601 | 4.4923 | 6.56382 | 6.6828 | 1.01813 |
| F | .. | 10 | 0.125 | 1.375 | 0.7483 | 0.80811 | 0.8223 | 1.01756 |
| G | .. | 10 | 0.125 | 1.375 | 1.1225 | 1.21221 | 1.243 | 1.02540 |
| $H_1$* | .. | 9 | 0.1585 | 1.669 | 1.741 | 2.89377 | 2.9280 | 1.01183 |
| $H_2$* | .. | 9 | 0.1585 | 1.669 | 1.741 | 2.89377 | 2.9445 | 1.01753 |
| I | 28 | 7 | 0.1655 | 1.167 | 1.374 | 1.66739 | 1.7355 | 1.04085 |
| J | 28 | 7 | 0.1655 | 1.167 | 1.994 | 2.41977 | 2.4994 | 1.03291 |
| K | 28 | 7 | 0.198 | 1.401 | 1.373 | 2.3931 | 2.541 | 1.06182 |

*$H_1$, normal flow; $H_2$, reverse flow.

# Basic Control Circuits For Squirrel Cage Motors

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**Some basic circuits for starting and controlling squirrel cage induction motors. Manual and automatic across-the-line starting circuits, reduced voltage methods, overload protection, reversing, and multispeed operation are included in the discussion.**

FOR ECONOMY and best performance the alternating current control for squirrel cage induction motors must be carefully matched to the characteristics of both the motor and the driven machine. For example, one machine may require automatic starting, stopping, and reversing, while another application would need only a simple across-the-line manual starter. A discussion of some basic types of controllers, their fundamental circuits, and how they function, may be helpful to designers who must select and apply a.c. control correctly.

According to NEMA definition, "An electric controller is a device, or group of devices, which serves to govern, in some predetermined manner, the electric power delivered to the apparatus to which it is connected." When operating, these electric controllers carry out one or more of their basic functions, such as accelerating, line closing, retardation, or reversing. Controllers that accelerate a motor to normal speed in one direction of rotation only are motor starters. To carry out their basic functions, controllers use devices such as pushbuttons, manual switches, control drums, magnetic relays, and magnetic contactors, as well as pilot control devices, resistors, rheostats, transformers and magnetic brakes. Diversified control devices are used in various electric circuits to meet the individual operating requirements of the machine or product.

In addition to the operating considerations of these control devices, attention must be given to the mechanical requirements. Motor controllers may be open-mounted or inclosed. Controller enclosures protect the control devices against atmospheric conditions, mechanical damage, and at the same time, prevent accidental contact with live parts. Most enclosures are non-ventilated, including such standard types as general purpose, water tight, dust tight, and hazardous location. Choice of the controller enclosure depends largely on the location of the mounting and the surrounding atmospheric conditions. For example, outdoor mounting of a controller would require a water tight, non-ventilated inclosure while a controller installed indoors under normal atmospheric conditions would use a general purpose non-ventilated cabinet.

Selected control devices are connected into electric circuits in various ways to provide the individual operating needs of the motor and the machine. Thirteen basic circuits for controlling a.c. squirrel cage induction motors are discussed in the following, ranging from simple across-the-line starting schemes to the more complicated reduced voltage systems.

## ACROSS-THE-LINE STARTING

MANUAL ACROSS-THE-LINE STARTING. The simplest form of a.c. motor starter has a set of normally open main contacts, as shown in Fig. 1. When in a closed position, these contacts connect the motor directly to the source of power. The starter is simply a hand operated switch that starts and stops the motor and is commonly used for controlling fractional horsepower squirrel cage motors. Typical uses of across the line starters are for small machine tools, fans and pumps. These starters are usually mounted near the machine.

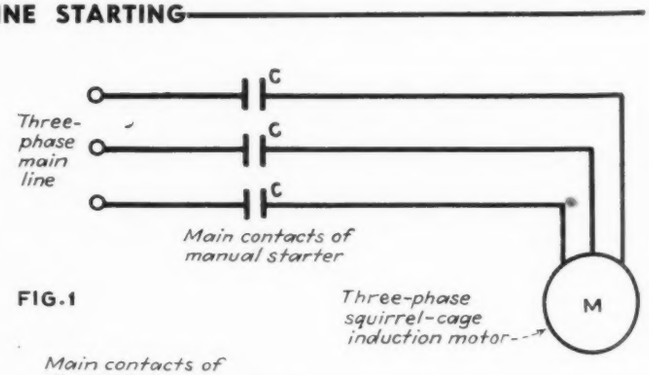


FIG. 1

ELECTRICALLY OPERATED STARTING. Replacing the manual switch by a magnetic contactor lets the main contacts be operated electrically, as shown in Fig. 2. A manual pilot device, such as a snap switch, in series with the magnet coil controls the main contactor. The pilot device and control coil circuit form the pilot circuit. Pilot devices for controlling the magnetic line contactor coil may be either hand operated by selector switches, push buttons, or snap switches, or they may be automatically operated by float switches, thermostats, pressure regulators, or vacuum regulators.

TWO WIRE CONTROL. One form of hand operated pilot devices is the maintained contact type, where the pilot contacts remain either open or closed as last operated. As shown in Fig. 2, when

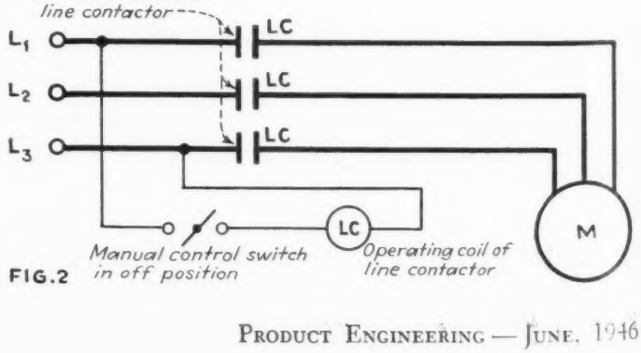


FIG. 2

the pilot device is closed, the coil of the line contactor is energized and closes the main contacts. However, if the line voltage decreases to a low value or fails completely, the line contactor drops out disconnecting the motor from the line.

On restoration of line voltage, since the contacts of the pilot device are still closed, the line contactor recloses and automatically restarts the motor. This pilot circuit arrangement is known as two wire control, or a low voltage release circuit, and is often used for automatic pumps and compressors.

THREE WIRE CONTROL. A second form of manual pilot device is the momentary contact type. Usually two pushbuttons are used, the start button having normally open contacts and the stop button having normally closed contacts. Momentarily depressing the the start button closes the contacts until the button is released, and then the contacts resume their normal open position. Pressing the stop button opens the contacts, releasing it closes the contacts.

A schematic diagram of a motor starter using a momentary contact type pilot device is shown in Fig. 3. An additional contact has been added to the line contactor and is connected directly across or in parallel with the start button contacts. This auxiliary,

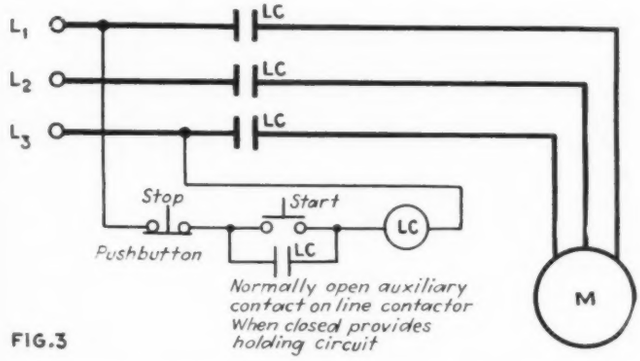


FIG.3

or maintaining contact opens and closes at the same time as the main contacts. Momentarily depressing the start button closes the line contactor, which remains closed because of the circuit established across the pushbutton contacts by the maintaining contact. With low line voltage or failure of line voltage, the line contactor opens and remains open even after restoration of line voltage because the maintaining contact remains open. In contrast to the low voltage release circuit, to restart the motor the start button must be depressed again. This type of pilot circuit provides low voltage protection, since the motor does not restart itself. Three wire control is often used on machine tools as a safety measure so the machine will not restart unexpectedly and endanger the operator.

OVERLOAD PROTECTION. In addition to starting the motor, the control circuit must protect the motor from dangerous overloads while it is running. The load on a motor is indicated by the current in amperes the motor draws from the line. The amperes flowing in the winding generate heat, raising the temperature of the motor above the surrounding atmosphere. The motor is rated on the basis of a normal temperature rise in doing normal work. However, if the motor does more than its rated amount of work excessive current is required from the supply thus creating an excessive temperature rise.

Electric motors are designed to withstand a certain degree of overload before damage occurs from overheating. The greater the overload on the motor the shorter the length of time the motor is able to operate without damage. To detect and prevent damage because of dangerous overload conditions, overload relays in motor starters and controllers automatically affect the operation of the main line contactor which disconnects the motor from the line. Overload protection in a circuit guards both the motor and controller against the damaging effects of overcurrents.

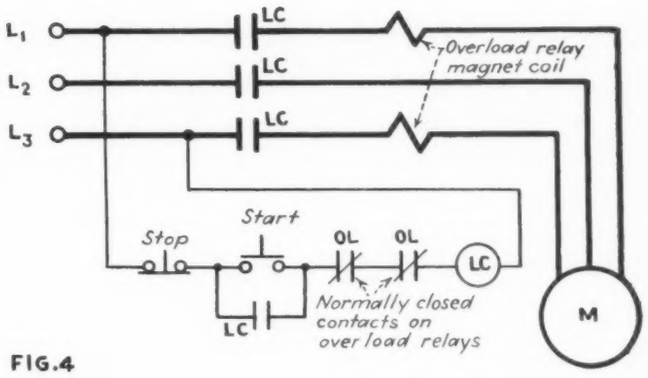


FIG.4

An overload relay generally uses a heater or magnet coil through which the motor current passes. The normally closed contact of the overload relay is connected in series with the device that it operates or controls.

Overload relays do not operate when the current drawn by the motor is of a normal value. If the motor draws more than normal current, the relay operates and trips open its contacts. To match the thermal characteristic of the motor, overload relays may delay the tripping time from several seconds to several hours. The speed of operation depends on the current passing through the relay coil. A high current shortens the tripping time whereas a low overload current lengthens the tripping time. When the trip time varies inversely as the square of the current, the relay is called an inverse time delay relay.

A typical schematic diagram of a motor starter having overload protection and low voltage protection is shown in Fig. 4. The overload relay contacts are connected in the pilot circuit in series with the line contactor, the maintaining contact, and the stop button. With a sustained overload on the motor, the overload relay trips and opens the circuit to the line contactor coil thus disconnecting the motor from the line. Unless the overload relay is of the automatic or electrical reset type, the contact will remain open after tripping until manually reset. Some magnetic starters and controllers use a manual reset button extending through the enclosure door. By using a pilot circuit, certain types of overload relays can be reset electrically.

AUTOMATIC STARTERS—TWO WIRE CONTROL. Automatic motor starters control motors that operate intermittently to maintain a condition, such as keeping a compressed air tank at a constant pressure. When the air in the tank is being used, the pressure inside the tank drops. When the tank pressure drops to a predetermined value, the automatic starter starts the motor, as shown in Fig. 5. The motor runs until the normal pressure is reached and then the control stops the motor. After the motor is once started by the manual pilot control device, automatic pilot devices do the stopping and starting. In the compressor and the tank example, the pilot device would be an automatic pressure switch with the two wire control circuit providing low voltage release.

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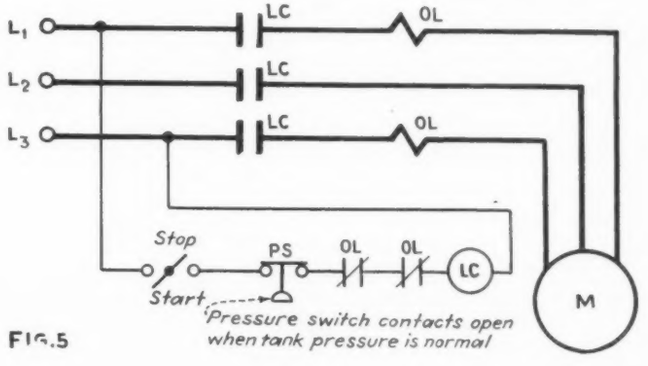



FIG.5

AUTOMATIC STARTERS—THREE WIRE CONTROL. For automatic motor starters requiring low voltage protection, the circuit in Fig. 5 is changed from two wire control to three wire control. In addition, the motor starter in Fig. 6 uses an additional low voltage protection relay or control relay. The control relay is operated by the start pushbutton and the relay has an auxiliary contact that keeps the relay closed after the start button is released. Provided the pressure switch is closed, a second contact on the control relay,

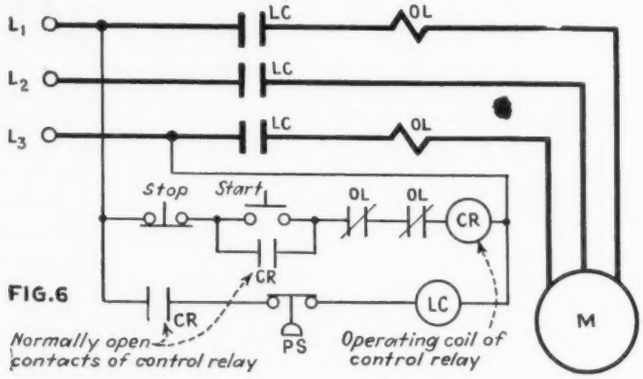


FIG.6

when closed, operates the line contactor. With this pilot circuit, the line contactor can open or close dependent on the operation of the pressure switch. However, if there is a loss of line voltage or an overload on the motor, the control relay will drop out opening the circuit to the line contactor and disconnecting the motor from the line. To restart the motor, the start button must be depressed again.

SELECTOR SWITCH CONTROL. Magnetic starters or controllers may employ a selector switch in the pilot circuit as shown in Fig. 7. This manual three position selector switch provides the operator with two methods of motor operation so the switch is marked "Hand, Off, Auto." In the hand control position, the motor is started by pressing the start button and the pressure switch has no effect on the subsequent motor operation since the pressure switch contact is short circuited. Thus, in the case of the air compressor, the pressure in the tank would have to be regulated by hand or by some similar method. With the selector switch turned to the

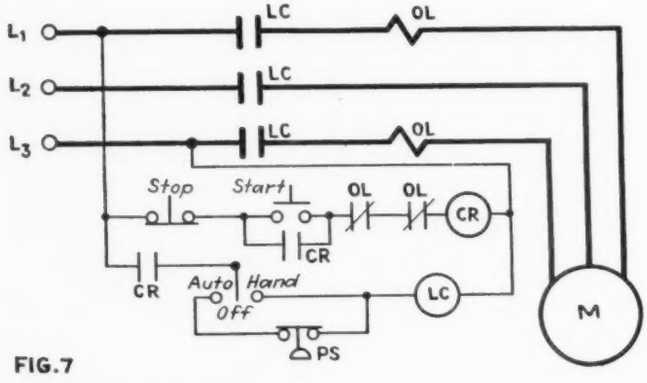


FIG.7

automatic position, the starting and stopping of the motor is automatically controlled by the pressure switch after the start button has been pressed. In the off position the motor cannot be started. Three position selector switch control is often used for refrigeration and pumping systems.

SAFETY INTERLOCK CONTROL. For greater protection, an additional automatic pilot device is added as shown in Fig. 8. This circuit is similar to the one shown in Fig. 7 except that the contacts of a high pressure switch have been added in the pilot control circuit. The high pressure switch is a safety device to stop the compressor when the maximum safe air pressure is reached

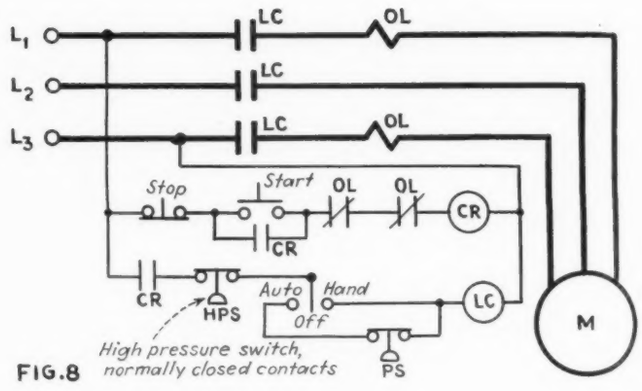


FIG.8

regardless of the position of the selector switch. When the high pressure switch contact opens, the operator must release the excess pressure in the tank before the compressor motor can be restarted.

MULTISPEED A.C. MOTOR CONTROLLERS. Alternating current motors for industrial applications often require operation at more than one speed for use when driving such devices as pumps, fans, and blowers. However, it is extremely difficult to change the speed of an ordinary squirrel cage induction motor since the rotor circuit is fixed. Adjustable speed can be obtained by changing both the supply frequency and voltage impressed on the stator winding of the motor. However the additional motor generator and control increases the cost and space requirements. To overcome this disadvantage, multispeed squirrel cage motors are often used when the application requires two, three, or four, motor speeds.

Adjustable speed is obtained by changing the number of effective motor poles, that is by having two or more windings or by connecting one winding in more than one way. Ordinarily in a two-speed motor, the slower speed is one-half the speed and one-half the horsepower output of the higher speed. Controllers for multispeed squirrel cage motors permit the selection of the speed desired. The controller also provides overload protection at each speed. Since the current drawn from the line by the motor at low speed is less than at high speed, two sets of overload relays are used.

A typical wiring diagram of a magnetic controller for a two-speed two-winding squirrel cage motor is shown in Fig. 9. This circuit uses low voltage protection as well as overload protection at each speed. The start-slow and start-fast push button pilot devices are changed somewhat from those previously described. These pilot devices are of the double throw type having one set of normally open momentary contacts and another set of normally closed

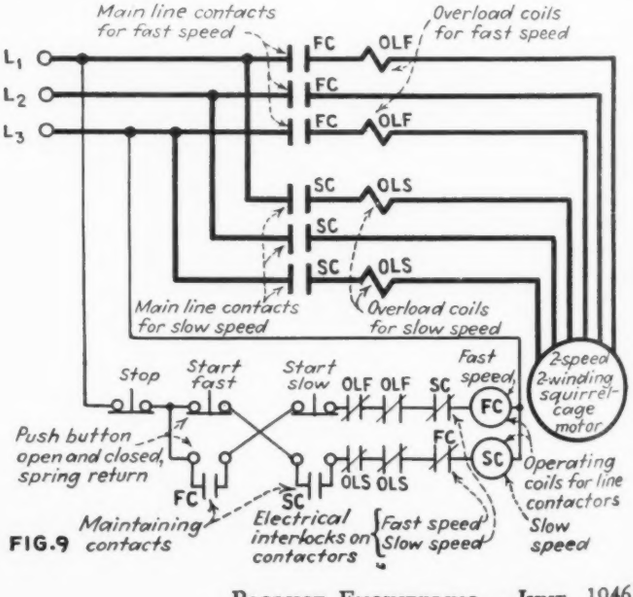


FIG.9

momentary contacts. Speed selection is obtained by operating either the slow or fast start button, thus completing the circuit to the proper main line contactor. Multispeed controllers providing three or more speeds would use a selector switch in place of push buttons and a separate line contactor for each additional speed. Multispeed controllers are used on air conditioning units, fans, and certain machines where close speed adjustment is not needed.

Electrical and Mechanical Interlocks. For each line contactor, *FC* and *SC*, a set of normally closed auxiliary contacts have been added as shown in Fig. 9. These auxiliary contacts, or electrical interlocks, are connected in series with the coil of the opposite line contactor and prevent inadvertently closing of both contactors at one time. Thus if the fast contactor is closed, the slow contactor cannot close without first de-energizing the fast contactor. Sequence circuits use many electrical interlocks to insure correct operation of one relay or contactor that is dependent on the other.

In addition to electrical interlocks, mechanical interlocks are used on multispeed and other type controllers to safeguard correct operation. For instance, when two contactors are employed, as in Fig. 9, mechanical interlocks may be arranged so that when one contactor is closed, it blocks the other contactor from closing. Mechanical interlocks are particularly effective where tilt and vibration are prevalent such as on shipboard applications.

Reversing Controllers. Two or three phase a.c. induction motors can be reversed by simply reversing one phase. It is important that the magnetic reversing circuit be arranged so as to accomplish motor reversal at the will of the operator. Reversing is obtained by interchanging two line leads within controller.

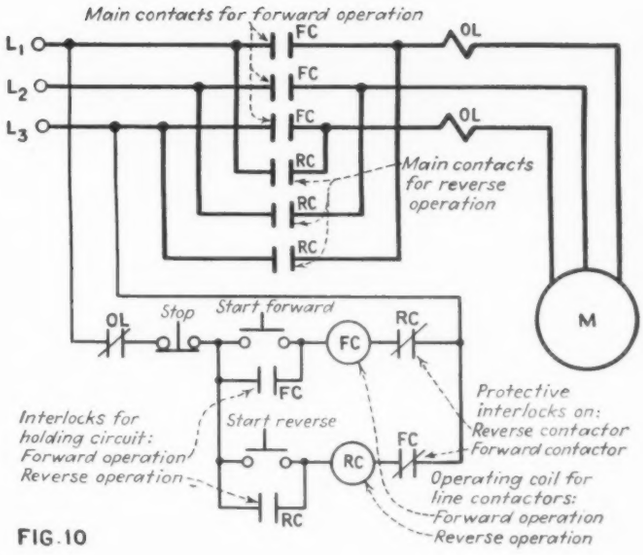


FIG. 10

The reversing controller shown in Fig. 10 is similar to a two speed controller described in Fig. 9, except that one pair of the overload relays is eliminated since the motor horsepower is the same in either direction of rotation. Two electrical interlocks and a mechanical interlock prevent the forward and reverse magnetic contactors from inadvertently closing at the same time. Two start pilot devices are required but only a single stop push button.

## REDUCED VOLTAGE STARTING

All the starters and controllers previously described are of the across-the-line type, and the motors were connected directly to the full line voltage by a manual switch or a magnetic contactor. Across-the-line starting of a.c. motors has many advantages because the control unit is inexpensive, easy to install, and extremely simple to maintain.

However, when a.c. induction motors are started directly across-the-line, they draw from four to ten times their normal full load current from the line. This inrush current gradually subsides to normal full load current as the motor approaches full speed. The heavy inrush current drawn by the motor in starting often causes line disturbances if the power supply is inadequate or if the motor is large. To limit the starting current and decrease line disturbances, motors are often started by compensators, primary resistors and star-delta connections.

Compensators. Compensators use an autotransformer to reduce the voltage supplied to the motor during the starting period thus limiting the inrush currents. A typical autotransformer starter using time limit acceleration is shown in Fig. 11. In this circuit, two magnetic line contactors are used one with five poles and the other with three poles. The five pole contactor starts the motor by connecting it to the autotransformer, and after the proper time interval, the three pole contactor connects the motor directly across the line.

The sequence of operation of the contactors is controlled by the pilot circuit. The small control transformer supplies the 110 volts required by the motor of the timing relay. Momentarily depressing the start button energizes the start contactor which is mechanically as well as electrically interlocked with the run contactor. The five pole start contactor completes the connections to the autotransformer which is provided with adjustable voltage taps at 50, 65 and 80 percent of line voltage. The tap is selected that gives the best starting condition for the motor and that part of autotransformer is left permanently connected at *B* as shown. After a pre-set period of time, the motor driven time delay relay causes control relay to close its contact CR. This opens the start contactor and causes the control circuit to close the run contactor thus connecting the motor directly across the line.

Primary Resistor Starting. Primary resistor starters for a.c. motors use resistors to reduce the voltage supplied to the motor

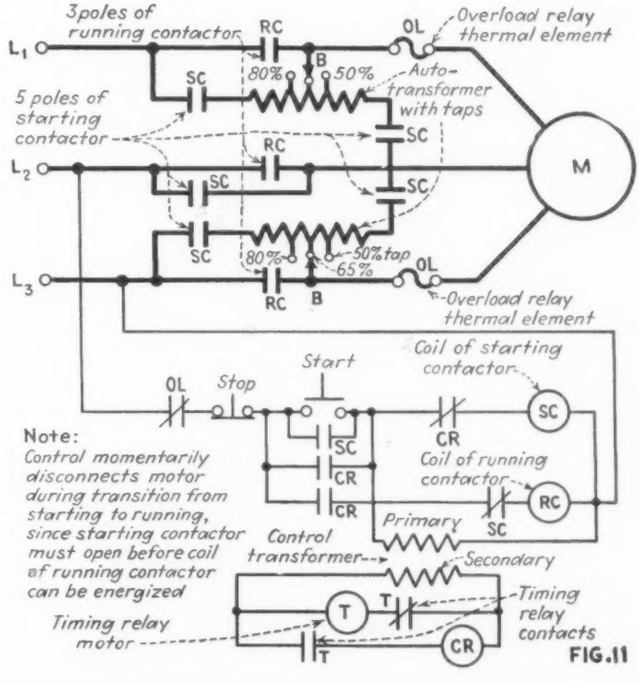


FIG. 11

on starting. This method of reduced voltage starting is used when smooth acceleration is desired and is often preferred over the autotransformer type starter for this reason.

Smooth acceleration is obtained because as the motor accelerates the current decreases, thus lowering the voltage drop across the starting resistance and automatically increasing the voltage supplied to the motor. Since the motor circuit is not disconnected momentarily during the acceleration period, as is necessary with compensators, smoother starting is obtained.

Resistor starting is inefficient since the power dissipated in the resistors is comparatively high. For this reason, resistor starting is generally used for low starting torque applications rather than for heavy loads.

The simple primary resistance starter shown in Fig. 12 requires two three pole magnetic contactors, a main line contactor, and an accelerating contactor, timing device, a set of starting resistors, and overload relays. The starting resistors in each leg of the line have equal ohmic values and watt capacity.

On pressing the start button, the main line contactor closes connecting the motor to the line through the resistors. The main line contactor in closing starts the time delay relay which after a definite period of time closes its contacts, thereby energizing the accelerating contactor. In closing, the accelerating contactor shorts out the starting resistors and connects the motor across the line.

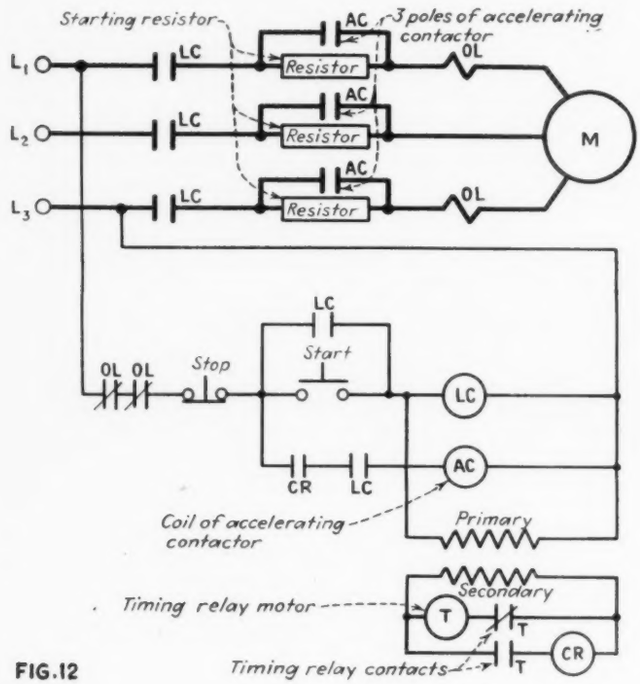
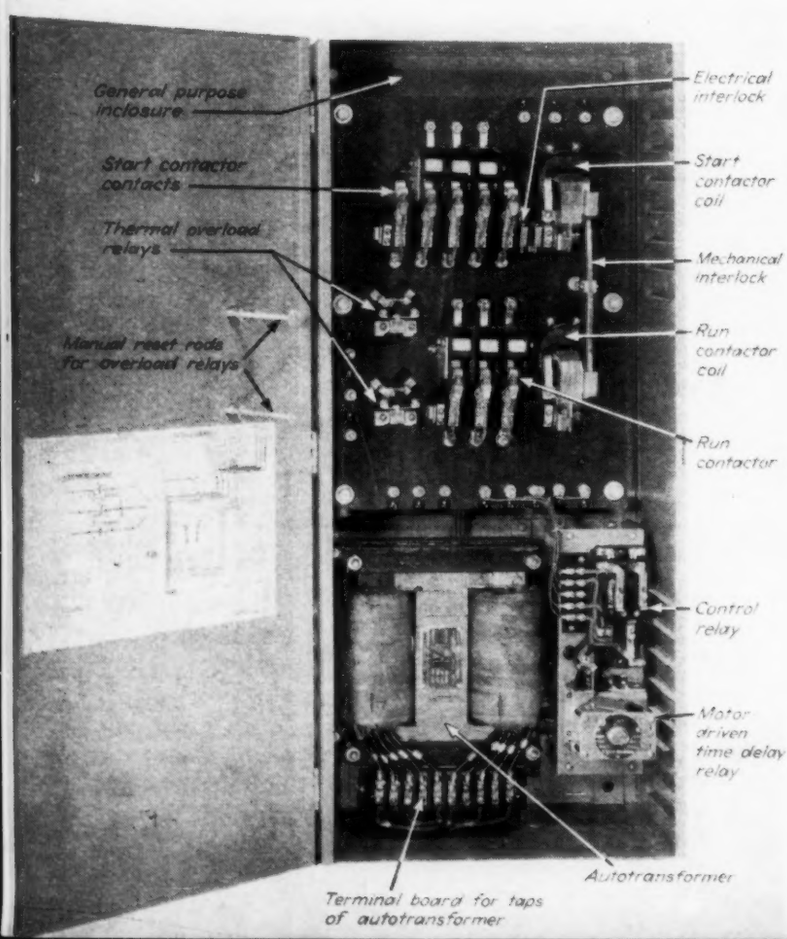



FIG. 12

Typical a.c. automatic autotransformer starter for 25 hp., 440 volt, 60 cycle motor. For safety of operation the start contactor and run contactor are both electrically and mechanically interlocked.




Star-Delta Starting. Induction motors that have external leads for each end of their three phase stator winding may be connected in either star or delta. Ordinarily, three phase, three wire squirrel cage induction motors are connected in delta, thus requiring only three external leads. With a delta motor connection, full line voltage is applied to each phase when across-the-line starters or controllers are used. However, with six external leads, the stator can be star connected for starting, impressing a reduced voltage of approximately 58 percent of line voltage across each motor phase.

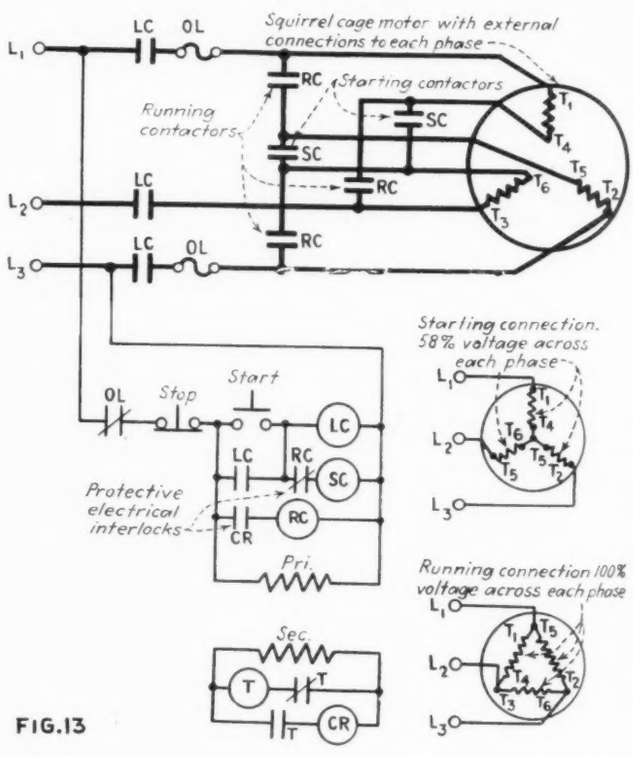
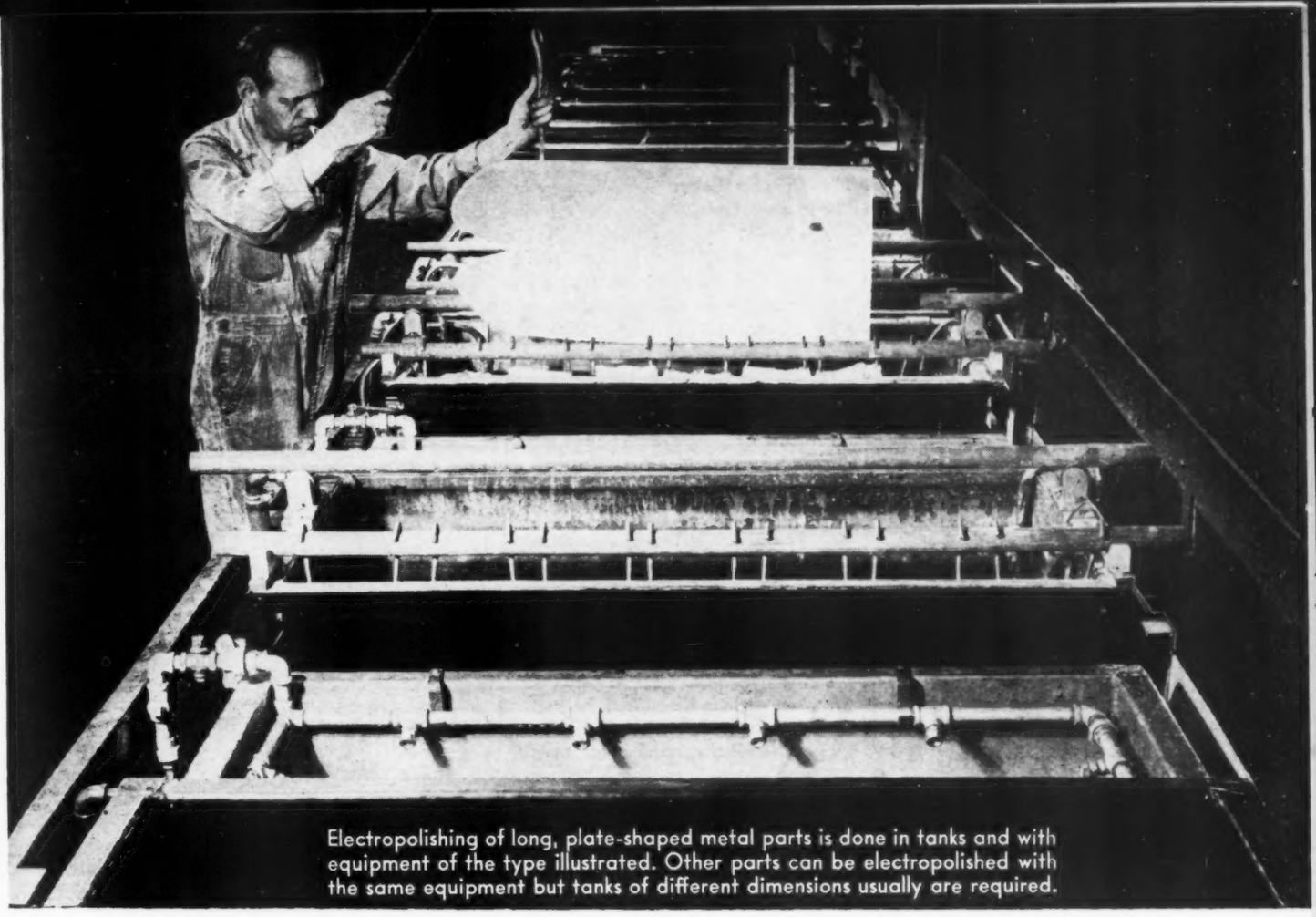



FIG. 13

The schematic in Fig. 13 shows a typical circuit for transferring from star to delta motor connection.

A magnetic star-delta starter circuit requires a main line contactor, start contactor, run contactor, timing relay, overload relays and a suitable pilot device. Momentarily depressing the start button closes the main line contactor and the start contactor connecting the motor in star. After a time interval determined by the timing relay, the relay de-energizes the start contactor coil and energizes the run contactor coil connecting the motor in delta and thus impressing full line voltage across each phase.



Electropolishing of long, plate-shaped metal parts is done in tanks and with equipment of the type illustrated. Other parts can be electropolished with the same equipment but tanks of different dimensions usually are required.

# Electropolishing Metals To Obtain Surface Finish

**CHARLES L. FAUST**
Battelle Memorial Institute

**Recent applications, advantages and limitations of the process. Diverse uses of the process are described; types of surface finishes for metals are compared; design data and information are given. Cost of typical processing equipment and relative costs of finished products are included.**

ELECTROPOLISHING attains metal surfacing without mechanical work being done on the metal. It is suited to processing surfaces so irregular in shape that mechanical methods of polishing are impracticable.

The electropolishing process is replacing automatic and hand operated machines for finishing metal articles to brilliant, mirror-like appearance, for machining parts to size, for removing burrs from stamped, ground, punched, drilled and other machined edges, and for getting surfaces ready to final finishing by electroplating, painting, lacquering, japanning, heat bleackening and anodizing.

The process might be considered as electroplating in reverse. The part to be polished becomes an anode instead of a cathode as in electroplating. When the current is applied, a minute film on the surface is dissolved and flows off the surface into the electrolyte.

There are many combinations of acid and alkali baths, technically suited for use as electrolytes, but only a few of them have practical industrial significance. About 80 such combinations are listed in an article on "Electrolytic Polishing of Stainless Steels and Other Metals" by Otto Zmeskal in the April 1945 number of *Metal Progress*.

Solutions of sulfuric and phosphoric acids are used in commercial electropolishing because combinations of these acids are suitable electrolytes for electropolishing many of the common metals and alloys—mild steel, high carbon steel, low alloy steel, austenitic stainless steel, ferritic stainless steel, aluminum and brass—under the same processing.

Zinc, copper, nickel silver and other alloys, and sometimes aluminum and brass also, require solutions having proportions of sulfuric and phosphoric acids of limited electropolishing utility. Commercial electropolishing of stainless steels is done in solutions comprising 55-60 percent citric acid, 15-20 percent sulfuric acid and water.

The sulfuric-phosphoric acid processes are

covered by patents owned by The Battelle Development Corporation, and the citric-sulfuric acid process by patents owned by Rustless Iron and Steel Division of The American Rolling Mill Company. These methods are considered the most practical today. Other methods are under development and are being tested in pilot production; hence, practical improvements may be expected. More than 75 patents have been issued.

Other types of electropolishing solutions have been developed and several are available for commercial use. Generally they contain phosphoric acid, or sulphuric and phosphoric acids, plus organic material, such as alcohol, glycerine, glycol and others. Although the organic materials are beneficial in some instances, the trend is to avoid the use of them because they make a more expensive electrolyte than the inorganic acids.

Since the electropolishing method of producing lustrous surfaces differs so greatly from the methods of mechanical polishing, there are applications where one method cannot be replaced by the other. There are also a large number of applications in which either method can be used successfully. The selection of which method then is largely a matter of economy.

## Electropolishing for Appearance

The most frequent application is finishing for appearance, where brilliance and color tone can be achieved better than polishing by mechanical methods, especially on rough, uneven surfaces. Since electropolishing gets into pits and depressions, stainless steel castings can be made to have a brilliant luster and clear color even in the rough state.

Brightening the bottom of pits, scratches, and tool marks sometimes reacts against the process. For example, stainless steel sheets, some carbon steel sheets and other materials contain impurities, which show up as slag particles, slag stringers, rolling seams or pits. When such a surface is mechanically polished, the metal is peened down or burnished over these defects effectively to conceal them. If such a surface is electropolished, the thin surface layers are removed and the defects are accentuated.

Another application of electropolishing is the manufacture of electric appliance parts from which a hand polishing operation is eliminated. A part can be formed out of a high-quality, cold-rolled steel, which is bright plated after forming and is then electrobuffed and chromium plated, to provide an acceptable appearance with a cost saving amounting to 1 to 5 cents per unit.

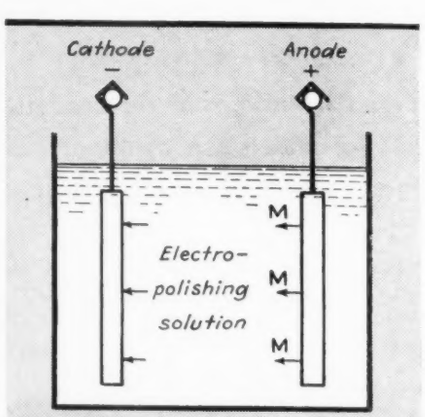
Brass stampings can be formed from cold-rolled brass sheet or strip, then electropolished and bright nickel plated before chromium plating, to show an over-all cost saving of as much as 3 cents per part. On brass stampings electropolishing may be used after bright nickel plating. In this instance, it would be called electrobuffing. Or, it might be that a two-stage electropolishing operation would be more economical; that is to say, electropolishing of the brass and electro-buffing of the nickel plate.

This ability to electropolish plated metal greatly widens the application for electropolishing. Obviously, a basic metal or alloy can be selected for reasons of its physical properties, or for reasons of manufacturing, and then it can be finished later by plating and electrobuffing the plated metal. As a consequence the purity control of the metal to be electropolished is in the hands of the engineers that manufacture the parts. If the basic metal is electropolished, its purity and properties are under the control of the metal manufacturer.

An excellent application for electropolishing is costume jewelry. Brass parts, however intricate in design and shape, after being electropolished, can be coated with a thin flash of gold, which may be brilliant enough or which can be touched up by a very light, wheel coloring operation.

A pebble finish can be obtained by electropolishing. The surface is prepared by shot blasting, sandblasting or vapor blasting. It is then electropolished to a brilliant luster, or is electropolished to a lesser degree resulting in an effect varying from a Butler finish, as found on quality silverware to a brilliant, sparkle finish. Such a finishing procedure has the distinct and practical advantage of hiding die marks or handling marks, which are introduced during processing, and of hiding fingermarks and scratches, which are introduced in service.

A pebble finish is a low cost quality finish because no preparation of the surface before electropolishing is required and the basic metal does not need to have a high-quality appearance initially. For example, hot-rolled and pickled metals can be used instead of the higher-priced better-surfaced metals obtained by cold rolling. A two-tone effect with various designs can be given by masking certain areas during the abrasive operation and prior to electropolishing the entire piece. Another two-tone effect, such as a relief pattern, can be obtained by selecting electropolishing of a surface having a stop-off applied in the form of a design.




**In electropolishing, the metal M dissolves removing a thin layer from the surface of the work. Protruding places dissolve at a faster rate so that a slick shiny surface results. The metal forms salts which dissolve in the solution and precipitate or plate out on the cathode.**

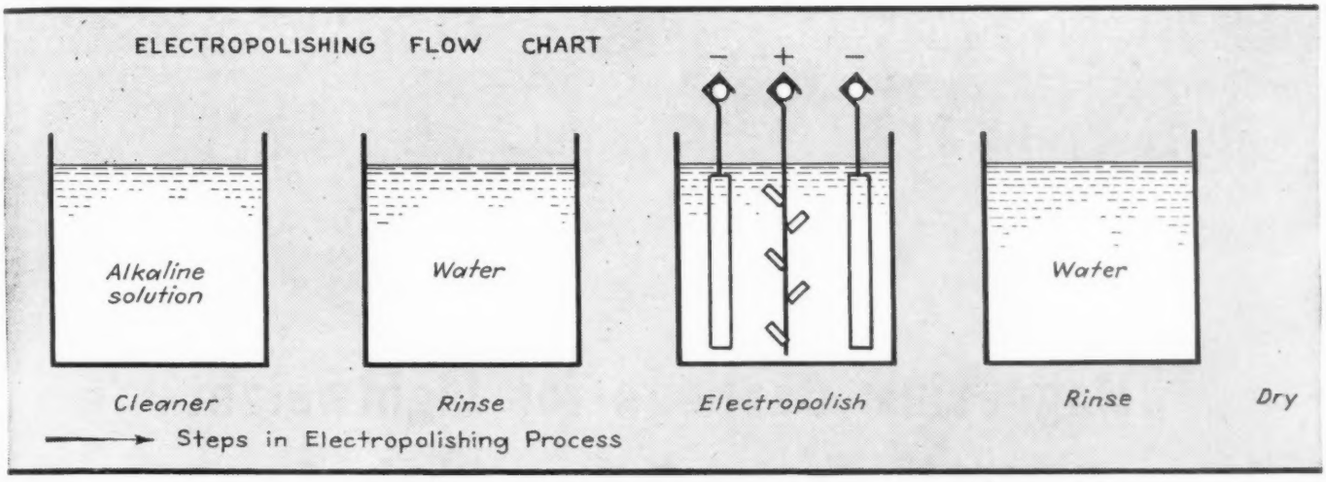
Sometimes electropolishing can take off burrs from stamped edges of complicated shapes and from inaccessible areas more readily than mechanical removal. Electropolishing has no particular technical advantage so that choice of method depends upon which is the cheaper. When the deburring operation can be combined with the finishing operation, the electropolishing method is invariably the cheaper. The deburring of gears, tools, fittings, metal stampings and parts that have cut edges often can be combined with the finishing operation. Stamped articles such as spoons, forks, knives, lids, cover plates, picture frames and instrument parts are hard to deburr by any other means.

In practically all cases the success of a deburring operation is dependent upon the size of the burr. Small burrs can be removed readily, and the edges can be broken and rounded. When large burrs exist, their removal entails an excessive loss of metal from other areas. This reduces the dimensions, often below permissible tolerances. At other times the quantity of electrolyte required to remove the burrs makes the method too costly. These objections can be overcome by the use of stop-off on the smooth surface area if an additional manual operation is not prohibitive.

Generally the removal of the heat scale can be done more cheaply by chemical pickling in inhibited acid solutions, by sandblasting or by vapor blasting. Occasionally electropolishing is used for scale removal. To achieve a satisfactory appearance, the scale must be uniform both in chemical composition and in thickness. A non-uniform scale breaks through in spots, with the result that the electropolishing action on the metal is greater in those places no longer protected by scale, thereby causing an irregular surface appearance. Light annealing scale, or the light tarnish that comes from spot welding, or from mild heat treatment, can be satisfactorily removed under electropolishing conditions for producing the brilliant, mirror-like finishes.

Dimensions on parts can be maintained because electropolishing is fast and can be controlled to provide uniform removal of metal. For example, plated steel and brass screws must be slighter smaller than standard to allow for electroplating to the proper size. Electropolishing uniformly removes metal from all surfaces; electroplating uniformly adds plating to maintain the dimensional tolerances of standard products.

In another application a cylindrical part was electropolished to remove 0.005 in. to 0.007 in. of metal from a 1/2 in. diameter and yet retain the final dimension within the




**Parts are cleaned before electropolishing either in an alkaline solution and water rinse or by a degreasing process. They are rinsed and dried after electropolishing.**

tolerance of plus or minus 0.0002 in. on the diameter. Other machining applications for electropolishing show that it is practical to improve the microinch finish on smooth surfaces. A mechanically ground steel surface, having a microinch finish of 50 to 60 r.m.s., has been reduced by electropolishing to a microinch finish of 25 to 30 r.m.s. Other surfaces with a 5 to 7 r.m.s. microinch finish have been electropolished to a 3 to 4 r.m.s. microfinish. In metal where electropolishing exposes inherent dirtiness such as slag particles, seams and pits, the microinch finish may not be improved by electropolishing.

## Electropolishing Before Plating

In its role as a finishing tool, electropolishing holds considerable interest to designers and engineers, especially where heavy plate is to be applied for engineering or mechanical purposes rather than thin plate for decorative or protective reasons. Mechanically working a metal to prepare it for electroplating introduces heating effects, strains, loose fragments of metal and derangement of the crystal structure in the surface layers. An electropolished surface is: (1) as free from strain as the original basic metal; (2) structurally characteristic of the body of the metal; (3) free from metal fragments and layers of broken-down crystal structure; (4) not influenced by heating effects from the mechanical working of the metal surface. All of these factors are of great importance where the bond zone is subjected to high stresses during functional use of a part having a heavy electroplate, particularly of iron, nickel, and chromium.

Milling, grinding, broaching and like machining operations impair the strength of the surface layer beneath the plating. For example, tensile specimens prepared by the Ollard test method showed fracture of heavy nickel plate on machined SAE-1010 steel at only 35,000 lb. per sq. in. when the steel was known to have a tensile strength of 100,000 lb. per sq. in. and the nickel plate was known to have a strength of 90,000 lb. per sq. in. In other words, the adhesion of the nickel plate to steel appeared to have failed at 35,000 lb. per sq. in. Microscopic examination revealed that the failure was actually by brittle fracture through a weak layer of the steel surface. Removal of this layer by electropolishing, and then nickel plating, provided bonds of such strength that failure in tension was at 90,000 lb. per. sq. in. entirely in the nickel plate. Consequently, perfect adhesion and the maximum bond strength were obtained.

The electrical requirements are equivalent to those for chromium plating. Rack designs, equipment, ventilation and handling problems are also analogous to those of chromium plating. Electropolishing has better throwing power than most acid-plating baths, so racking problems, and work placements are not complicated for plant use. Most commercial electropolishing is done at tank voltages between 6 and 12 volts.

Electropolishing can be done in fully automatic, semiautomatic, or manually operated equipment. Single and multistage processes can be set up, the latter often including cleaning, pickling, rinsing, and electroplating or anodizing stages.

## Equipment and Costs

With an equipment investment of $16,000 to $20,000, stainless steel, welded-wire shelves, 18 in. x 28 in. can be electropolished at a rate of 200 per hour. The estimated production cost is under 4 cents apiece.

An automobile windshield wiper arm, which has stamped sections of austeritic and ferritic stainless steel with extension bars in rolled cotton steel and contains inserts and springs in carbon steel and other parts of brass, can be electropolished after assembly. Clear color and attractive luster are produced by two minutes of electropolishing of the assembled unit. A tank 3 ft. deep by one ft. by 12 ft. long can handle 750 such arms plus 3,750 wiper blades per hour. The wiper blades may be processed as assembled with the rubber squeegee. The total equipment investment is about $20,000. Using reasonable values for direct charges, an estimated production cost for electropolishing is obtained at an average of 0.5 cent per part.

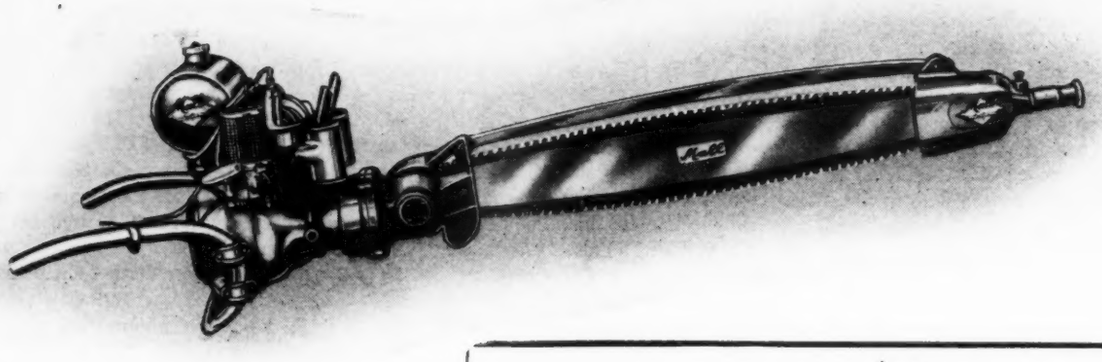
Costume jewelry, stamped in brass, is electropolished to a clear, brilliant color and luster. The contour and relief design of such a part offer no practical problems to producing a mirror brilliance by electropolishing, costing as little as 0.5 cents a part.

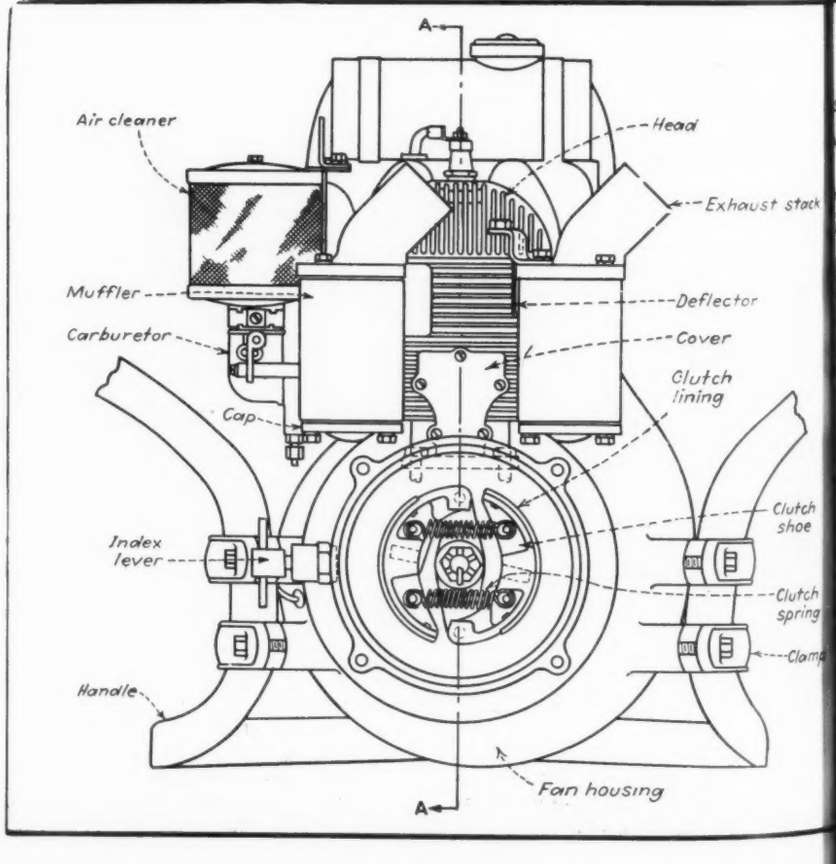
Refrigerator ice-cube trays of aluminum can be electropolished to an attractive, brilliant finish in five-minutes after stamping and forming. An anodozing treatment can follow with practically no loss of color tone and luster. A 3 x 3 x 10 ft. tank can turn out 450 ice-cube trays per hour, using a tank current of 6,000 amp. at 15 to 20 volts. The total equipment investment is about $25,000, and the unit production cost for electropolishing is about 3 cents per tray. This process electropolishes both the inside and the outside of the tray in the single operation. Reflectors of aluminum are electropolished with such excellent results that light reflectivity is superior to that from mechanically polished surfaces. In particular, short wave-length light, such as ultra-violet, is reflected with greater efficiency.

Small steel parts can be electropolished in the quantity of 15,000 per day, 7,000 of one type having 0.1 sq. ft. of surface, and 8,000 of another type having 0.2 sq. ft. of surface, being processed in a 4 x 3 x 13 ft. electropolishing tank. This unit handles 1,875 parts per hour for electrobuffing bright nickel plate. The result is a smooth, mirror-like, clear-color appearance at a cost of around 0.5 cent per part, exclusive of the small cost for extra nickel plate thickness required for electrobuffing removal.

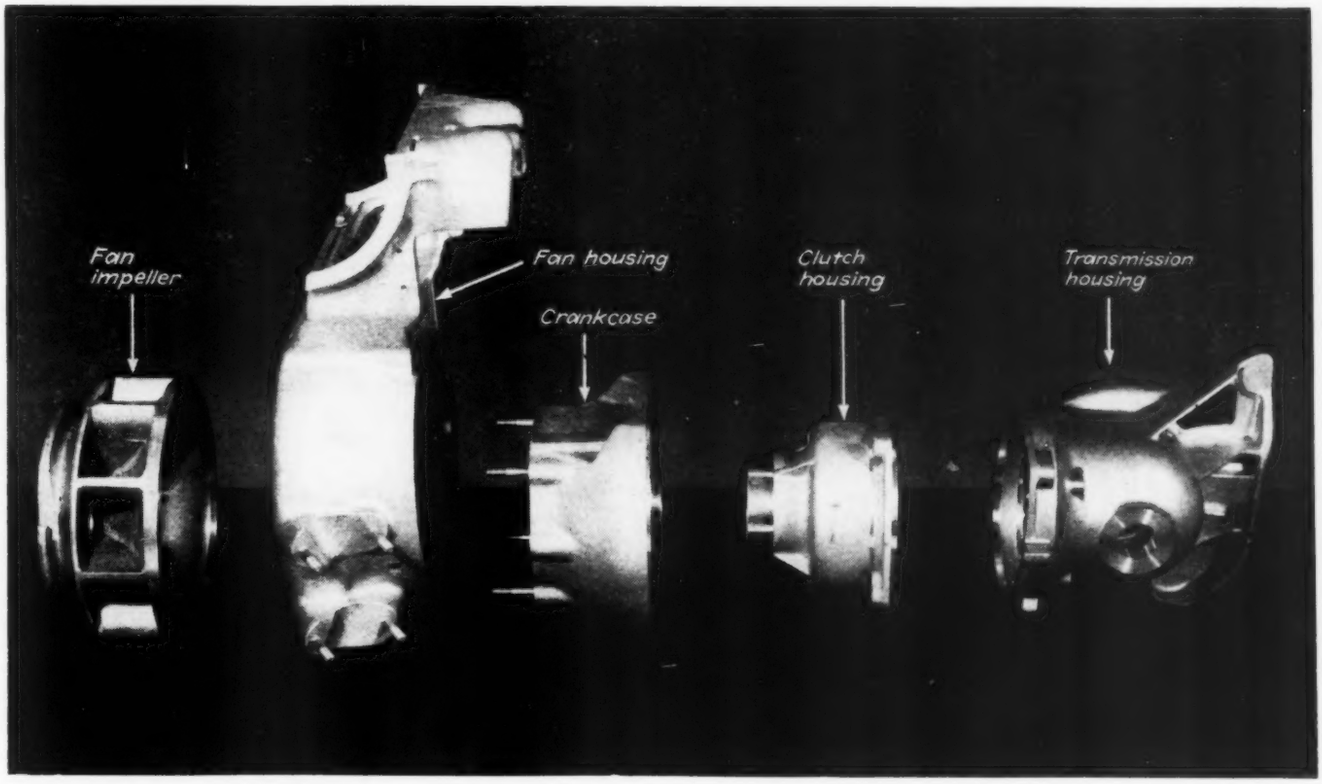
# PRODUCT DESIGNS

## Magnesium Castings for Lightweight Portable Engine-Driven Chain Saw

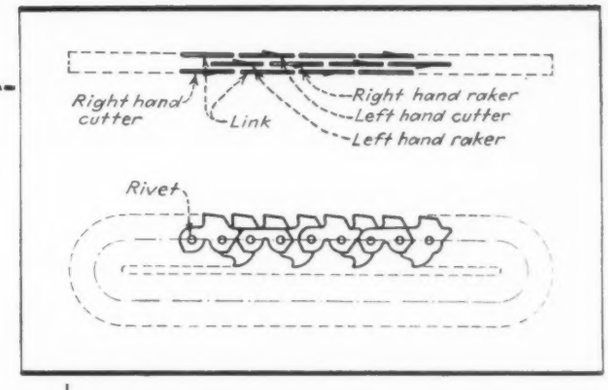




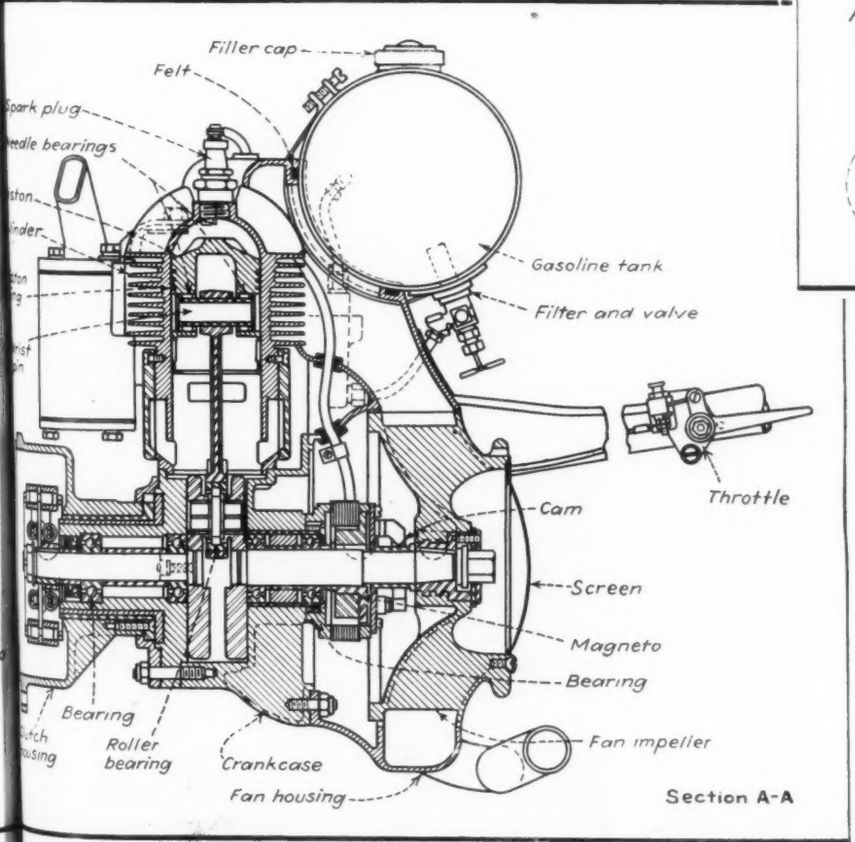

**MAGNESIUM CASTINGS** are used in the two-cycle engine of a portable chain saw to reduce weight. Developed by the Mall Tool Company the saw is available in 24, 36, 48, 60 and 72 in. capacities. Automatic centrifugal clutch engages the motor with the chain saw when the motor is brought up to operating speed. Thus, saw stops when forced too hard or operator removes hand from the throttle. Saw can be adjusted to cut vertically or horizontally by adjusting an index lever. Saw guide plate is reversible endwise and sidewise, thus giving a greater wearing surface.




**Five magnesium castings are used in the engine; fan impeller, fan housing, crankcase, clutch housing, transmission housing.**



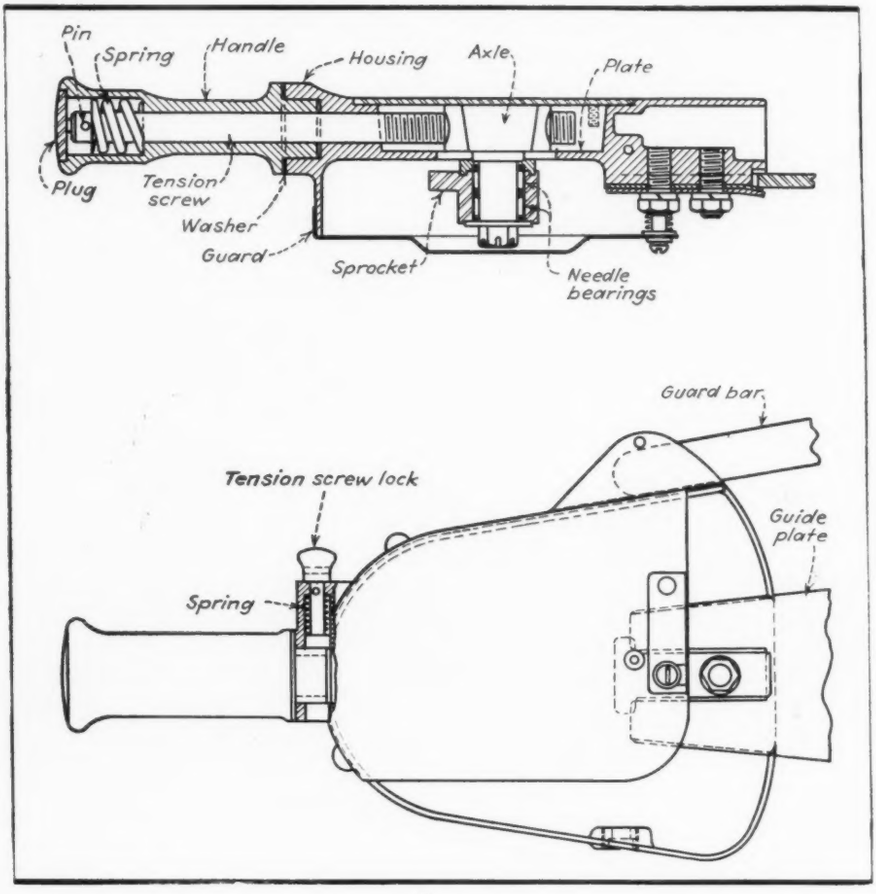

**Saw** is like a band saw but is made up of cutters, rakers and links riveted together to form the continuous saw. Rakers are shaped to fit the sprocket that drives the saw.




**Engine** has two mufflers. Crankshaft and connecting rod are steel forgings and piston and cylinder are aluminum alloy. Roller bearings are used at both ends of the connecting rod; one at the crankshaft and two in the piston bosses. Carburetor is of the single float, plain tube type. Air enters the carburetor through a large capacity air cleaner. Clutch is engaged by centrifugal force of shoes acting against the spring and requires no adjustment.

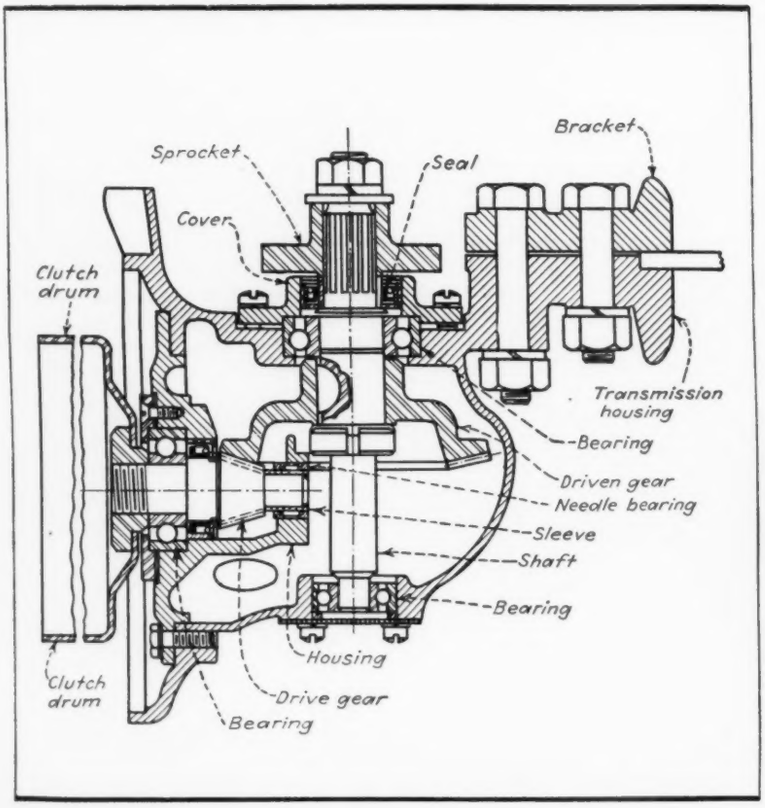
(Continued on next page)

## Chain Saw (continued)




**Tension** on the saw is maintained by a spring and can be adjusted by turning the handle. Tension screw is locked in position by a spring loaded pin. Sprocket runs on roller bearings.

**Transmission** has hardened bevel gears running in oil. Both bevel gears are straddle mounted to assure correct alignment. Drive gear is attached to the clutch drum.



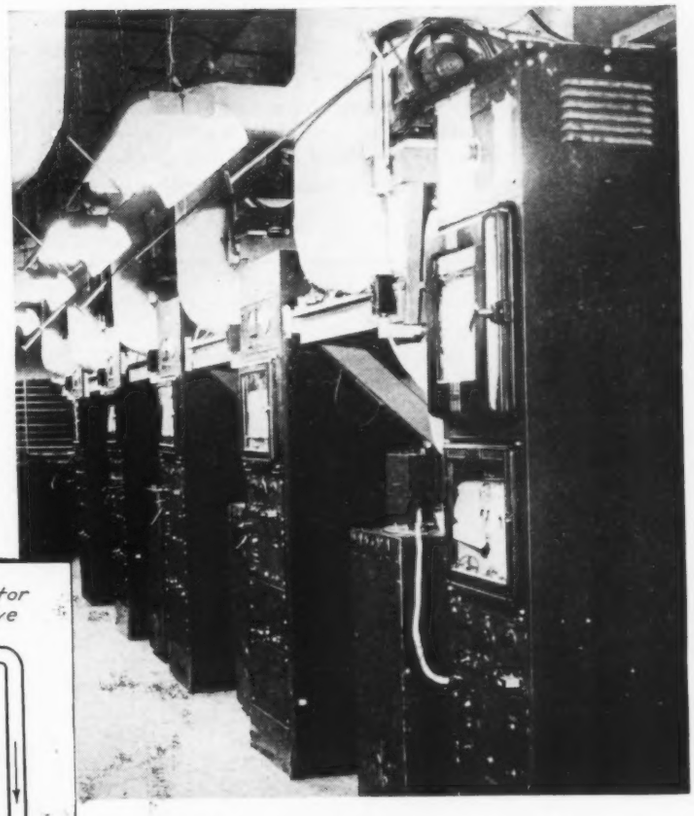

## Gage Measures Material Thickness With Air Pressure

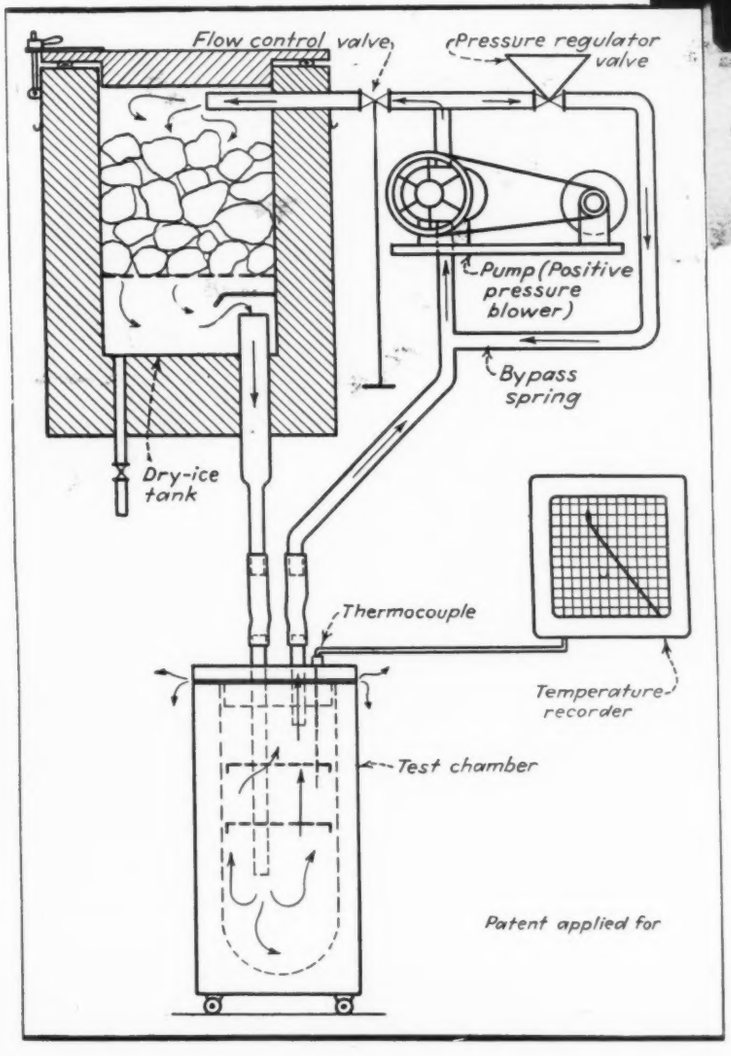
MEASUREMENT of sheet metal stock thickness using a pressure principle has been developed by The Glenn L. Martin Company. Gage consists of an inverted cup-shaped shell with a top wall of transparent material and the bottom rim edged with a rubber gasket. Dial indicator mounted inside the shell measures the sheet deflection when a predetermined vacuum is obtained within the shell. Gage is useful in checking bonds between layers of laminated materials. Instrument is calibrated for specific materials being inspected.

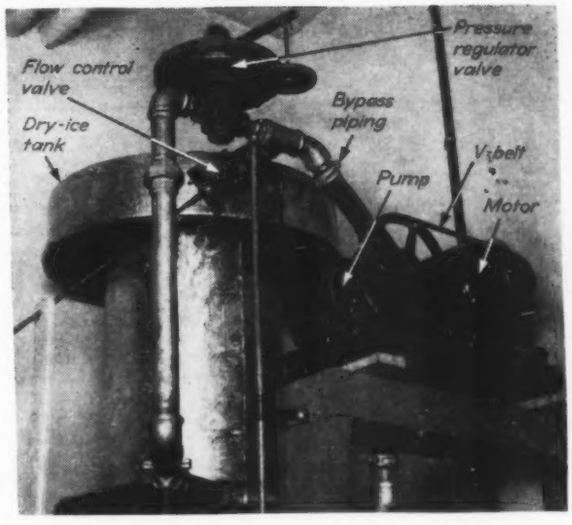
# Low Temperature Test Chamber Unit

**TEMPERATURE REDUCTION SYSTEM** employing a positive pressure blower and piping conveys low temperature gases from a cold source to a test chamber that can be portable. The cold source can be solid carbon dioxide, liquid air or evaporator coils. Developed for the North American Philips Co., Inc., by H. N. Brown, the unit was designed for temperature-testing electronic equipment. Using solid carbon dioxide, "dry-ice," the unit reduces the temperature in the test chamber at the rate of approximately one deg. F. per min. in the range of minus 76 to 212 deg. F. Test Chamber can be held at any desired temperature within this temperature range.

**Gases** are circulated by a pump, through a flow control valve into the dry-ice tank, where sublimation takes place at minus 109 deg. F. Test chamber is heated by hot air on strip heaters before temperature reduction begins. When flow control valve is closed, pressure regulator valve opens by-pass piping. Loose cover on test chamber allows expanded carbon dioxide to escape.



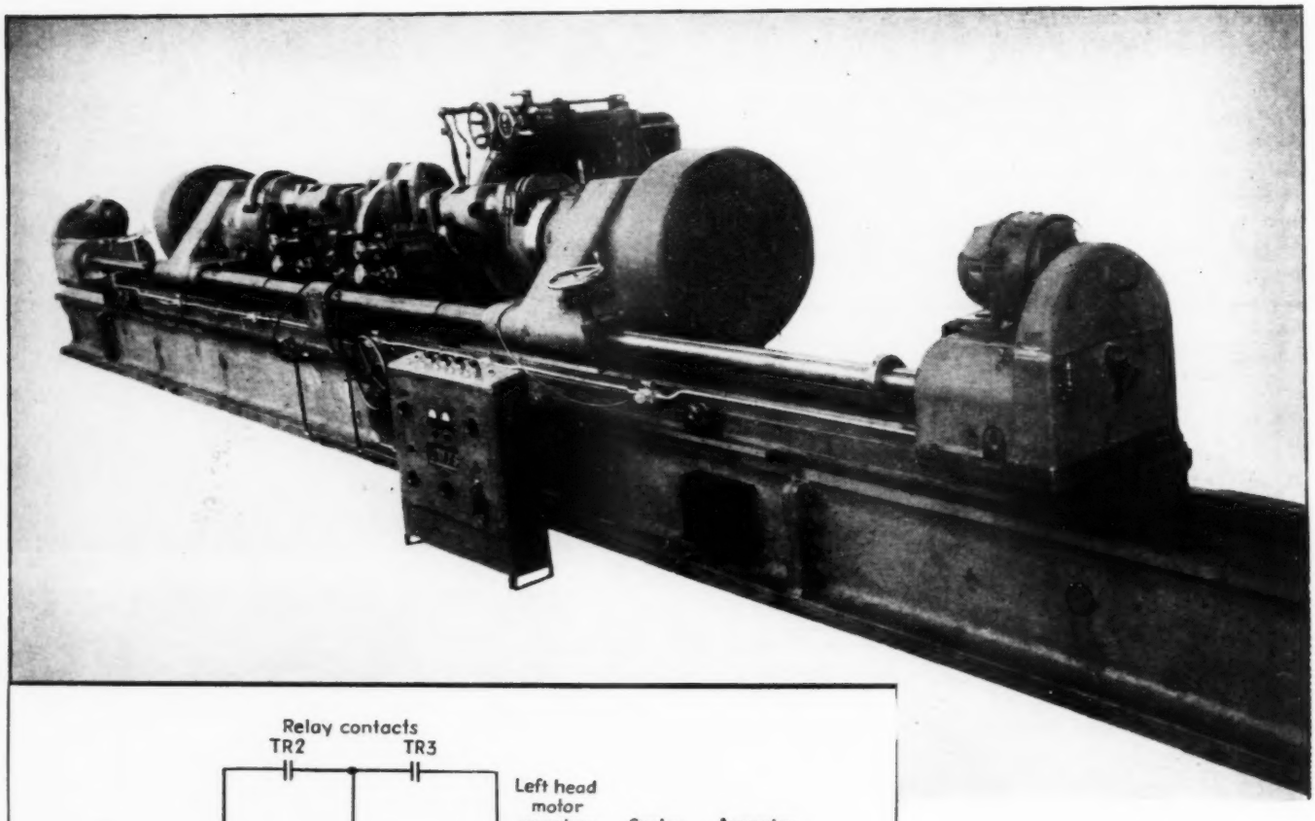


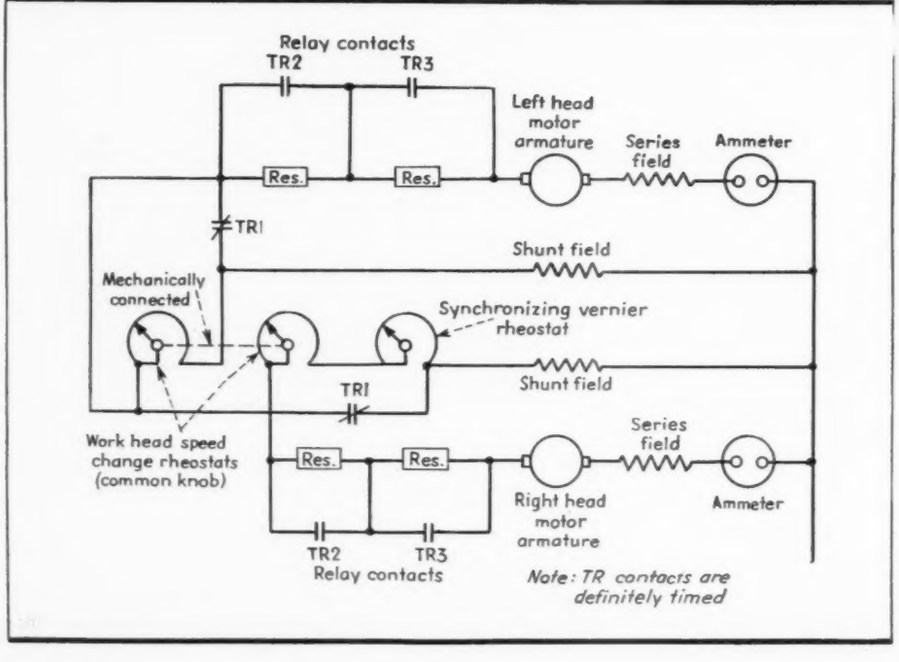




**Flow control valve** is manually operated. Valve acts to restrict flow through flexible rubber tubing and adjustment permits reduction of temperature at the desired rate. Pressure regulator is of the weight-loaded diaphram type. Pump is of the positive displacement double impeller type and operates against pressure and suction simultaneously. Electric motor drives pump through a V-belt.

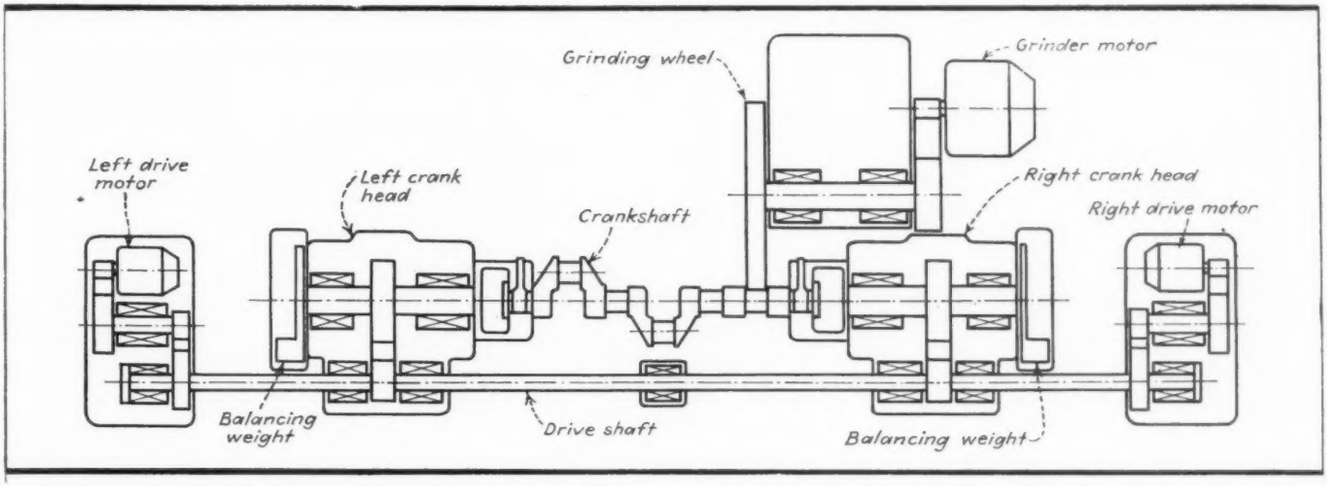
# Diesel Engine Crankshaft Grinder Uses Two Motors to Drive Crankshaft

DESIGNED to grind Diesel engine crankshafts bearings during manufacture and after crankshafts have been in service. This grinding machine, developed by the Landis Tool Company, has each crank head driven by an individual d.c. motor. Motors are connected through a common driveshaft. Equalization of motor torques, minimizing torsional deflection of work, is indicated by ammeters connected in the motor circuits. The ammeters also indicate when the crankshaft is in balance. Grinder will take crankshafts up to 40 in. diameter and 216 in. long. Single control knob adjusts both speed change rheostats.



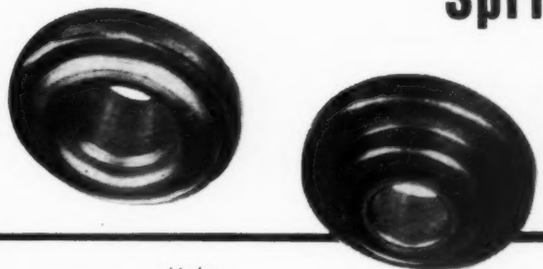


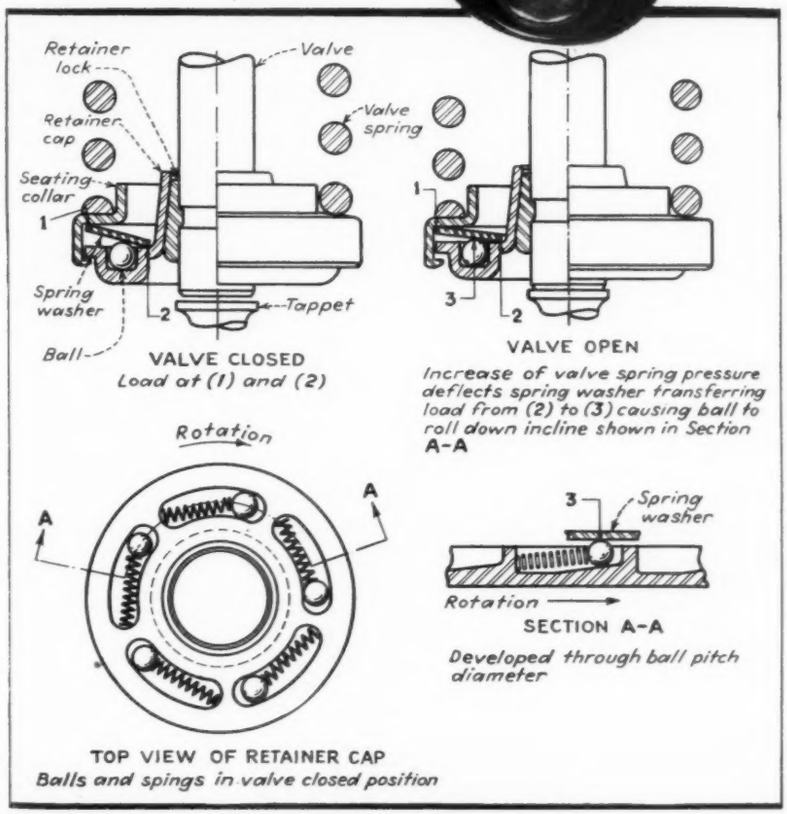

**Motor acceleration** is synchronized by mechanically timed accelerating contacts. Motor speeds are adjusted simultaneously by individual mechanically interconnected rheostats. Motor loads and speeds are equalized by vernier rheostat variation of the speed of one of the two motors and calibrated by simultaneous equal deflection of ammeters in series with the respective motors.




**Crankshaft unbalance** is corrected by adjusting the balance weights located on the outer end of each crank head spindle. Unbalance is visually indicated by oscillation of the pointers of the two ammeters. Crank heads are driven by the driveshaft connecting the two motors mounted adjacent to their respective crank heads.

# Spring Loaded Balls Rotate Engine Valves

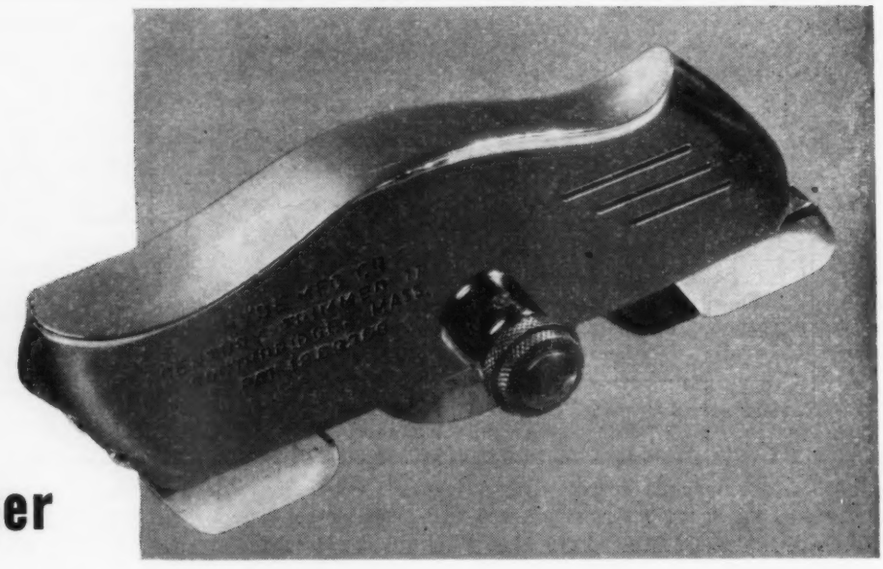




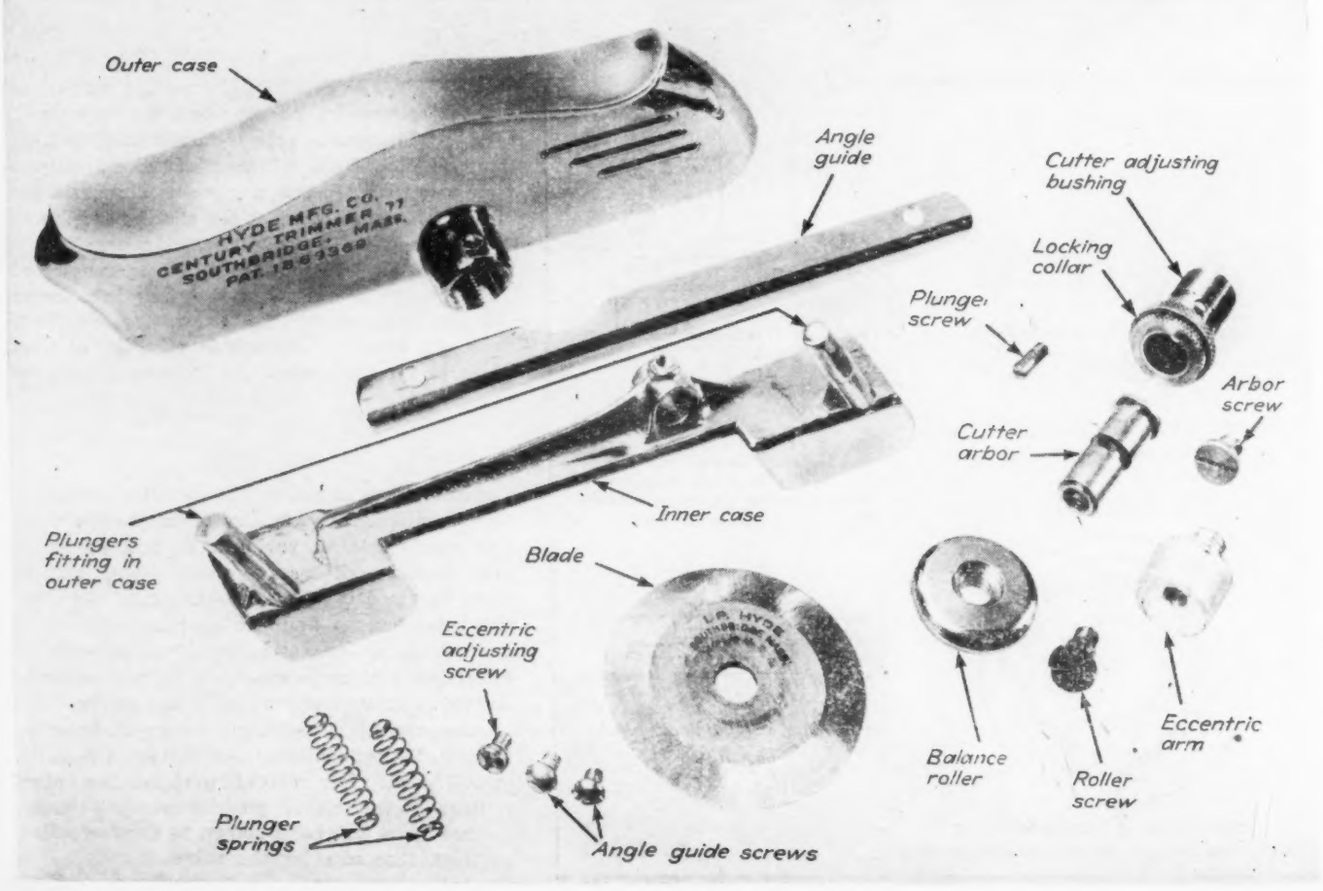

DEVICE DESIGNED to give positive rotation of internal combustion engine valves, has been developed by Thompson Products Company. Called the Rotocap, it is installed in place of the conventional spring retainer cap and requires no change in the retainer locks and neck. Valve sticking is reduced, since stem deposits are cut from the stem by the rotating action. Parts of the Rotocap are simple and dynamometer tests indicate that they have longer life than other parts in the valve mechanism. Tests have also shown an increase in valve life of from three to five times when the Rotocap is used.

**Retainer cap** includes five circular races in which balls are continually forced to the shallow end by small springs. A seating collar acts as the seat for the valve spring and is spun in place over the retainer cap. Between the retainer cap and the seating collar is a conical spring washer of sufficient strength to deflect only slightly when the valve is closed. As valve is opened the valve spring load increases and further deflects the conical spring washer, flattening it out and forcing the balls to roll down their respective races. As valve returns to the closed position conical spring washer rises and balls return to their original position, thus rotating the valve.

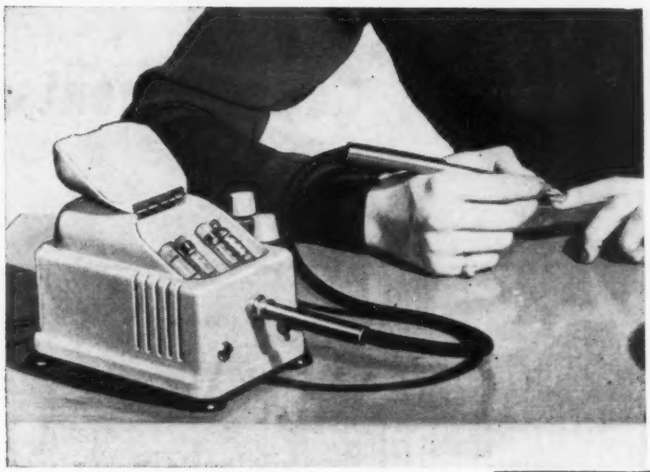
# Zinc Alloy Die Castings Simplify Wallpaper Trimmer



REDUCTION in the number of parts in a wallpaper trimmer has been possible with the use of two zinc alloy die castings. Designed by the Hyde Manufacturing Company, and known as the 777 Century Trimmer, chrome plating of the die castings and other external parts adds to its appearance. Trimmer gives a straight clean cut with every stroke since it can be adjusted to cut the paper at right angles. Trimmer can be disassembled with a screwdriver. Outer and inner cases are zinc alloy die castings. Blade is mounted on a steel arbor in a bronze bushing that can be moved to adjust the blade position. Balance roller is mounted on an eccentric which allows adjustment of roller so that a right angle cut of the wallpaper can be obtained. Inner case is held in position by a screw located in the rear plunger. The two plungers align the inner case in the outer case.



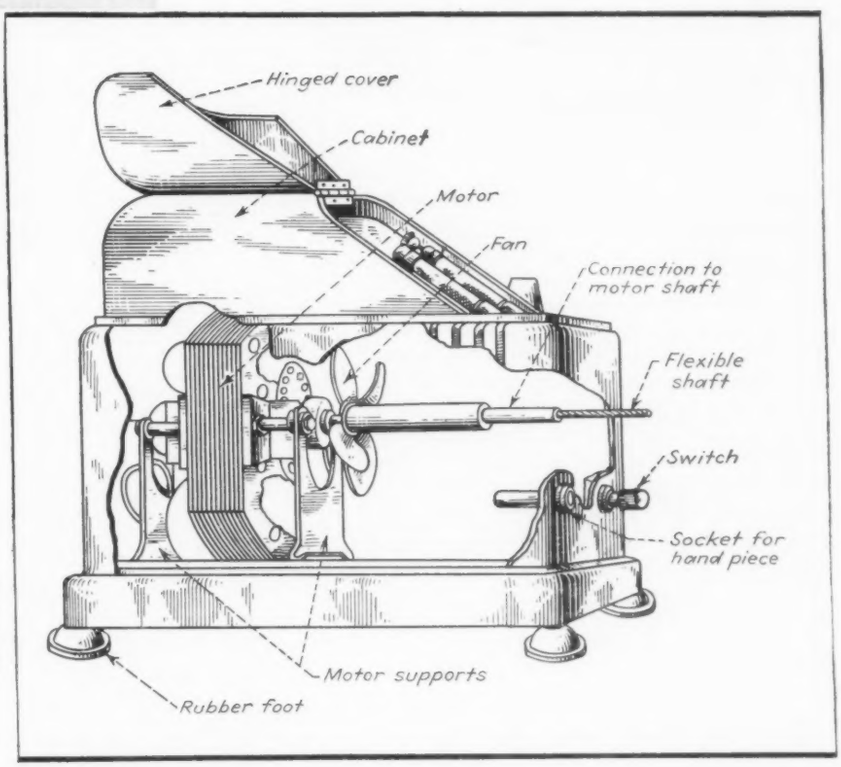
# Attachments Driven by Flexible Shaft In Compact Manicuring Device

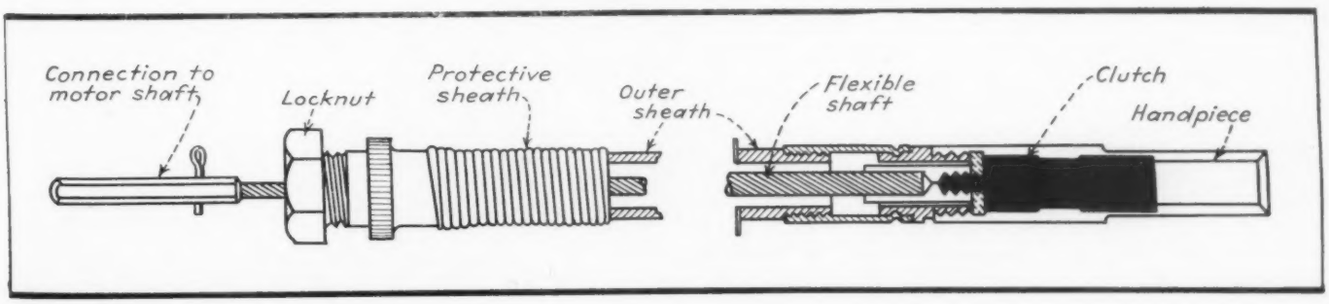


THE Beautiator Electrical Manicurist developed by Abar Manufacturing Company has five attachments; a file for nail shaping, a wand for cuticle rolling, a whisk for removing adhesions and dead skin from the base of the nail, an oil buffer for massage, and a dry buffer to remove all traces of moisture or oil film. File is a circular disk of garnet paper, fastened, by a bayonet lock, to the attachment. Felt buffer pads are screwed into the attachment by special threads inside the head. Wand has a cam arrangement inside the cylinder of the attachment that gives a reciprocating motion of 0.025 in. per revolution of the motor. Automatic clutch mechanism allows rapid engaging and disengaging of attachments while the motor is running. Attachments are housed under a hinged cover on the top of the machine.

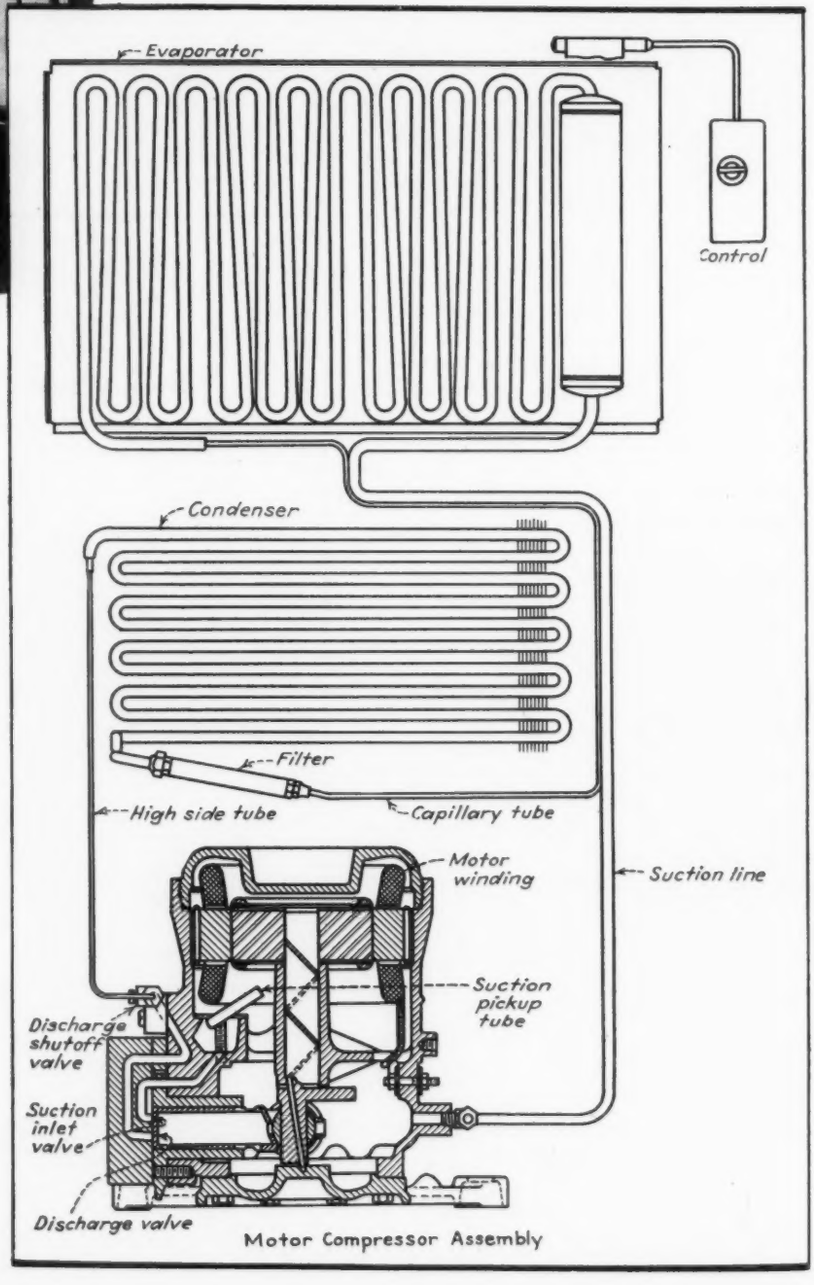
**Drive motor** is of 1/200 hp. and operates at 1,670 r.p.m. Motor speed is controlled within plus or minus 15 r.p.m. with or without proper operational load. Fan on motor shaft draws air for cooling from beneath the cabinet, around the motor, and out through louvres in the back of the cabinet, where it can be used to speed the drying of nail polish. Cabinet is molded from urea formaldehyde plastic.

**Flexible shaft** is connected to the motor shaft by a sliding shaft coupling that is hexagonal in shape. Other end of flexible shaft contains the automatic clutch mechanism. Sheath is protected from sharp bends at the handpiece and motor ends by a protective outer sheath.



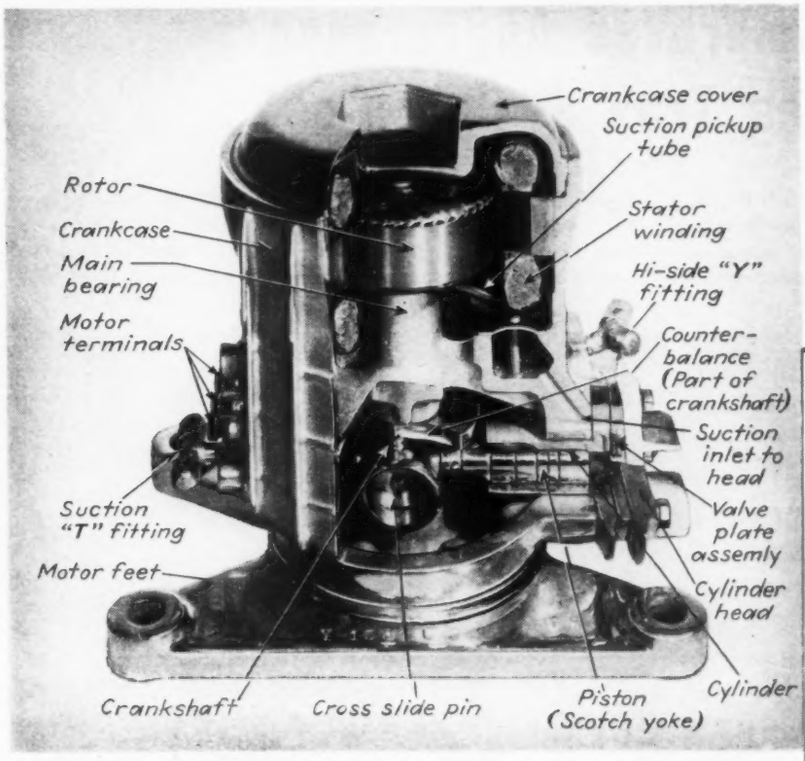



# 1946 Gibson Refrigerator Has Full-Width Freezer and Chilling Compartments

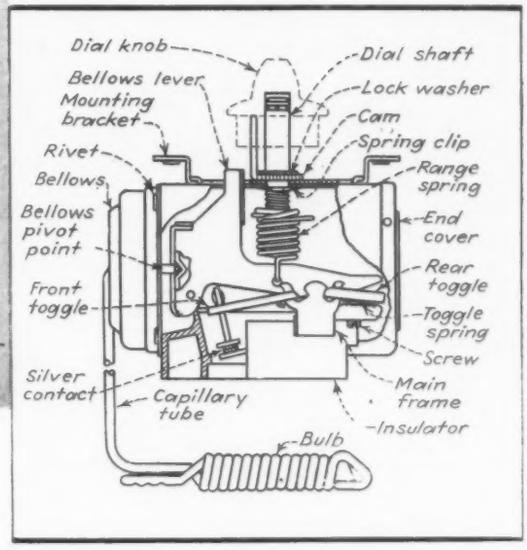



**FREEZING UNIT** extends full width of the food compartment and is completely surrounded by freezing coils in the 1946 model refrigerator, manufactured by the Gibson Refrigerator Company. A second full width compartment is located directly below the freezing unit and is used to chill foods and beverages. Design decreases shelf area taken up by defrosting receptacles that are eliminated in this model. Use of the full-width freezer design allows the temperature and humidity to be controlled by slowing down the air circulation thus eliminating condensation and dripping. Temperature in food compartment varies only 3 deg. between any two locations. Cabinet is of electrically welded steel construction.

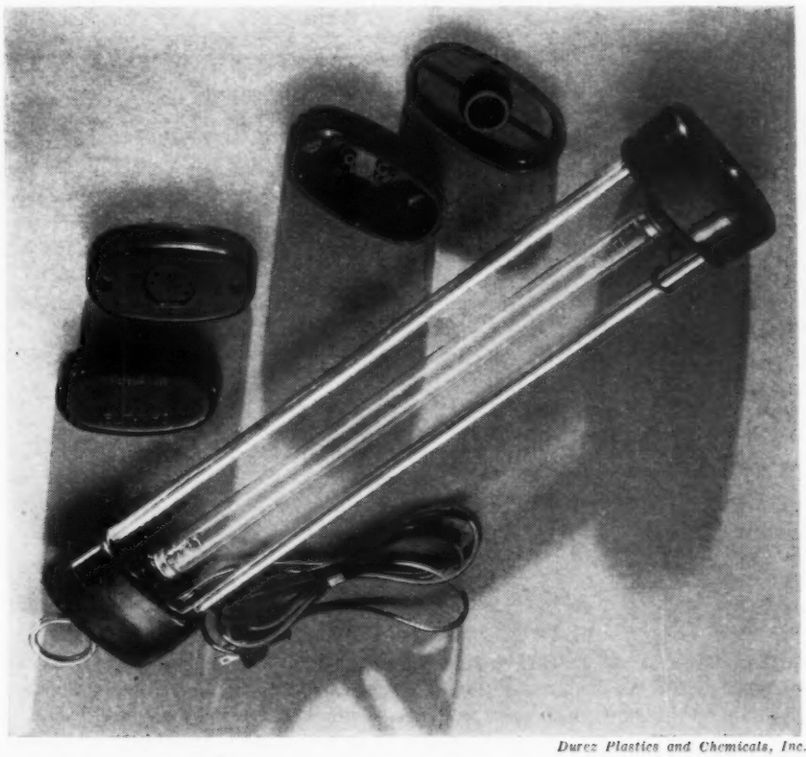
**Refrigerating system** uses Freon-12 as a refrigerant. Compressor is hermetically sealed. Condenser has natural-draft finned tubing with all joints silver-soldered. Evaporator is of plate, tube and boiler construction and is copper-plated.




**Compressor (left)** is of the reciprocating scotch-yoke type and has no shaft seals. Motor, of ⅛ hp., is equipped with an overload relay. Although hermetically sealed, the compressor can be easily serviced. Cylinder head, head valves and cylinder can be removed with capscrews located in the cylinder head. Cross slide and piston can be serviced by the removal of the base. Crankcase cover is screwed on and can be removed. Neoprene seal is used between the motor and cap.




**Temperature control (right)** has a 14 point selective switch. Temperature changes actuate a bellows that acts through a lever to open or close the toggle switch. Dial knob controls spring tension on bellows lever thus changing temperature at which bellows will actuate the toggle switch.



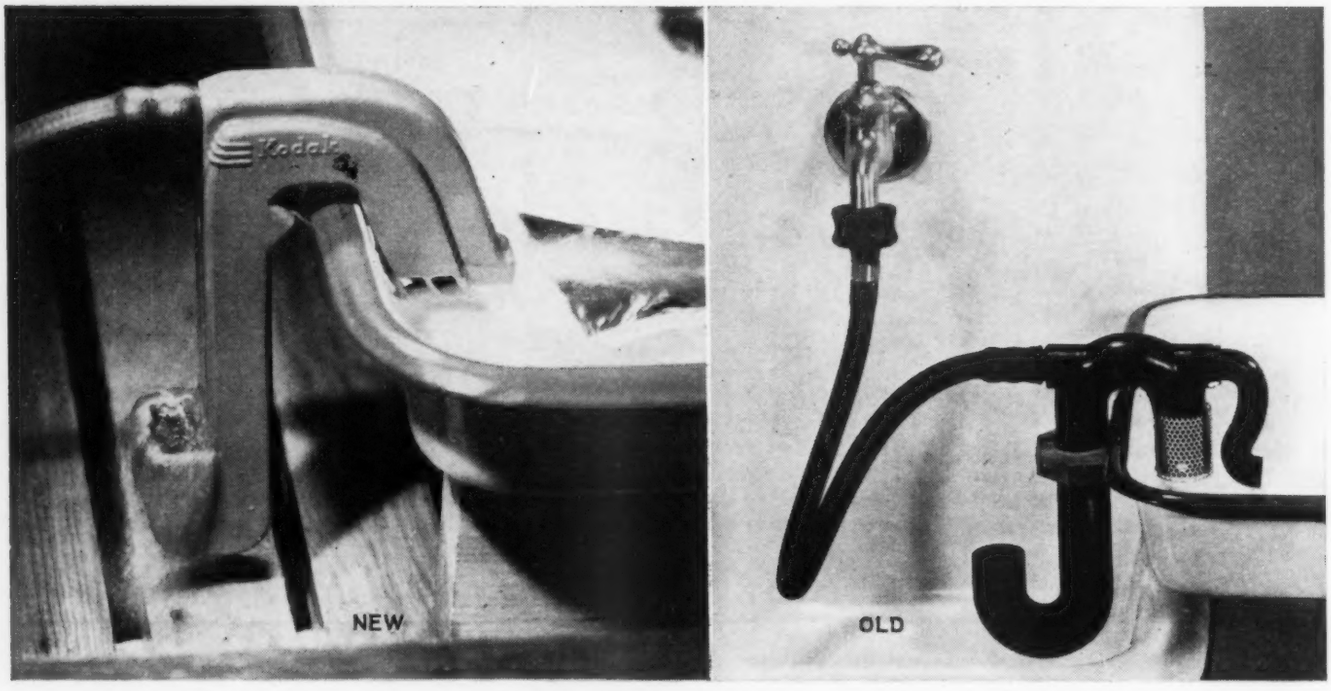
*Durez Plastics and Chemicals, Inc.*

# Germicidal Lamp Has Plastic End Fitting

GERMICIDAL LAMP developed for butcher store, refrigerators and showcases by the Sanilite Company has plastic end fixtures made from a phenolic molding compound. One fixture contains a small transformer and the other, the automatic starting mechanism. The two plastic cups that make up the end fixtures are filled with a nonhygroscopic dielectric material in which the electrical parts are embedded. Stainless steel rods carry the wiring between the ends of the lamp.

# Redesign Improves Appearance And Reduces Tray Syphon Cost

IMPROVED APPEARANCE and a 40 percent reduction in cost has been effected by the Eastman Kodak Company in the redesign of their Kodak Automatic Tray Syphon. New model is molded in grey cellulose acetate plastic. Nut-like rubber wedge that held the old model in place on the tray has been replaced by a stainless steel spring in the new model. Construction has been simplified and requires that only two halves be cemented together. Old design required the fitting together of three units.




# Random Notes on Reconversion

**Studebaker** has announced their new 1947 models in the Champion and Commander lines. Some of the outstanding features are new body styling, self-adjusting brakes, two section propeller shaft, box-section frame with front and rear kickups, interchangeable connecting rod bearings, new spring mounting with spring ends floating on rubber cushions, and improved body mounting. These cars will be described in the Product Design section for July.

* * *

**Neoprene** synthetic rubber is being formulated with abrasive particles into tiny resilient pellets that act as grindstones to smooth the rough edges of metal stampings, castings and precision-machined parts. Pellets are also used in tumbling barrels for deburring parts made of brass, steel or the light metals.

* * *

**Fluorescent** lighting fixtures designed primarily for use in kitchens and bathrooms have been announced by Sylvania Electric Products, Incorporated.

* * *

**Safety school bus** that will conform with the standards of different states has been announced by Reo Motors, Inc. Tooling is underway and production is expected soon.

* * *

**Conventional** type wringer washer has been dropped by the Westinghouse Electric Appliance Division, because projected costs of manufacture indicated that it would be impossible to sell at a competitive price. However, Westinghouse will make a complete line of automatic washers under the name of Laundromat.

* * *

**New lamp** developed by the Westinghouse Lamp Division is the most brilliant ever developed for commercial use. Consisting of a 1000 watt tubular bulb the lamp uses mercury vapor as a light source.

* * *

**Nylon bristles** are again being used in nine types of brushes for home use. Combs made of nylon are also available and are virtually unbreakable and can be cleaned in boiling water.

# Standards Cannot Stagnate Progress

OBVIOUS BENEFITS that have resulted from interchangeable bolts, nuts, lamp sockets, spark plugs and many other items have created the incentive to apply the principles of standardization generally. Recent announcement of the expansion of the activities of the American Standards Association to include standardization of manufactured consumer goods is an indication of the trends in that direction. Some engineers alarmed by this trend, have expressed the fear that national standardization will be carried to such extremes as to stagnate design progress by preventing the engineer from exercising his originality and ingenuity.

Two groups are required to establish the industrial acceptance of a standard. One draws up the standard; the other puts the standard into effect. If the designer refuses to recognize a standard, no power other than economic pressure can compel him to observe it. Cost considerations or marketing requirements may make it profitable to adopt a sound standard, but if the use of the standard cannot show a profit to the manufacturer or the user of the product, it will be ignored and factually will not be a standard. Such unwise and unrecognized standards are sometimes an annoyance, possibly creating some confusion, but they never prevent the designer from improving the product.

Unwise standardization that tends to choke progress destroys itself. Sound standards grow of their own strength and contribute to progress.

G. F. Nordenholt

# Fundamentals of Servomechanisms How to Select and Apply Them

**S. W. HERWALD**
Central Engineer, Westinghouse Electric Corporation

**Functional elements of servomechanisms are explained and illustrated by several typical examples. Characteristics of fourteen types of error detecting systems, nine types of amplifiers, and six methods of error correction are charted, compared, and discussed, along with some hints on designing servomechanisms.**

RECENT DEMAND for precise control of position and speed in industry has resulted in increased use of servomechanisms for controlling sectional paper mill drives, steel rolling mills, tracer milling machines and other industrial applications. During the war, these same principles solved many difficult control problems in new developments such as gunfire control, automatic pilots, and radar antenna positioners.

Servomechanisims are a class of automatic regulators that perform the basic function of keeping a regulated quantity matched to a reference quantity. Four important required characteristics of this type of control are: (1) fast response, (2) high accuracy, (3) unattended control, and (4) remote operation. Although there are many simple servomechanism applications, such as a thermostat controlling the furnace that heats a home, these four characteristics are increasingly significant as the difficulty of the control problem increases.

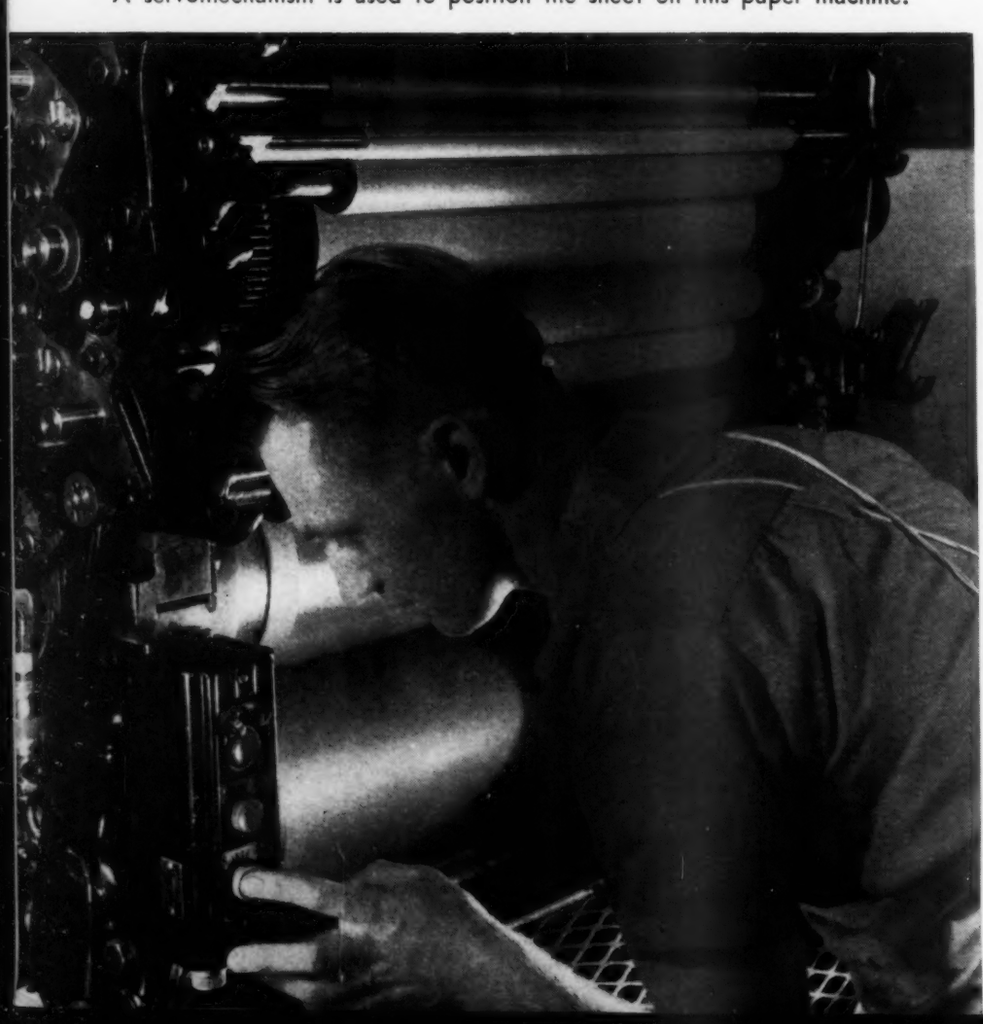
A servomechanism consists of three basic elements: (1) An error detecting device; (2) an amplifier; and (3) an error correcting device.

As shown in Fig. 1, each serves a functional purpose in matching the regulated quantity to the reference quantity. The error detecting device determines when the regulated quantity is different from the reference quantity. It then sends out an error signal to the amplifier which in turn supplies power to the error correcting device. With this power the error correcting device changes the regulated quantity so that it matches the reference quantity. The closed loop in Fig. 1 comprised of the error detecting device, the amplifier, the error correcting device, and the regulated quantity, is characteristic of all servomechanisms.

Any quantity can be regulated, such as voltage, speed, temperature, position, direction or torque. Any quantity also can be used as a reference quantity. The reference quantity need not be the same as the regulated quantity provided the proper error detecting device is employed. For example, it is possible to control the speed of a turbine so it will vary linearly with outside temperature; the speed of the turbine being the regulated quantity and the outside temperature being the reference quantity. However, most practical problems want to match two similar quantities, such as regulated position against a standard position, or regulated speed against a standard speed.

The error detecting device of Fig. 1 measures both the reference quantity and the regulated quantity, as indicated by *A* and *B*, and detects when they are not similar. When they are not similar an error signal is produced, represented by e if the output is electrical, or *x*, if the output is mechanical. The measuring units within the error detecting device must be the same. For example, in the case of the turbine governed by outside temperature, if the temperature is measured as a function of voltage by a thermocouple, then

A servomechanism is used to position the sheet on this paper machine.



the speed of the turbine is also measured as a function of voltage by a tachometer perhaps. When the voltage representing the reference quantity or outside temperature, is compared to the voltage representing the regulated quantity or speed, the difference obtained is also a voltage. This small difference voltage is the error signal. It varies in magnitude with the amount the turbine speed is different from the required speed for a particular outside temperature, and it has a polarity depending upon whether the turbine speed is higher or lower than the required speed.

In Fig. 1, the amplifier is merely a means of using the low power level signal e or x from the error detecting device to control the error correcting device, represented as load L. Typical industrial devices such as generators, valves, relays, and electronic tubes are commonly used as amplifiers in servomechanisms.

The error correcting device of a servomechanism actually does the work of regulating by producing an output C, as shown in Fig. 1. The error detecting device and amplifier serve only as a means of properly controlling the error correcting device so as to make the regulated quantity match the reference quantity. Typical error correcting devices include electric motors, gas engines, hydraulic pistons, and fuel burners.

The disturbance shown in Fig. 1 represents load variations affecting the regulated quantity; for example, the generator voltage drop with load for a voltage regulator, or the temperature drop in a room with decrease in outside temperature for a temperature regulator.

Applied control as shown in Fig. 1 is the controlled variation of the reference quantity in order to obtain desired changes in the regulated quantity. A common example of applied control to the reference quantity is the change in setting of a room thermostat, thus changing the reference temperature for the room. Both the applied control and the disturbances to the regulated quantity are independent, and upset the previous existing balance between the reference quantity and regulated quantity. Servomechanisms restore this balance between reference and regulated quantities continuously and automatically.

## Error Detecting Devices

The error detecting device has a great number of practical forms, and some representative types are given in Table I. Each error detecting device, regardless of whether it is electrical, hydraulic, or mechanical, performs three distinct operations:

1. Measurement of the reference quantity, designated by A,
2. Measurement of the regulated quantity, designated by B,
3. Produce an error signal, designated

(Continued on page 468)

FIG. 1—BLOCK DIAGRAM OF FUNCTIONAL ELEMENTS OF SERVOMECHANISMS

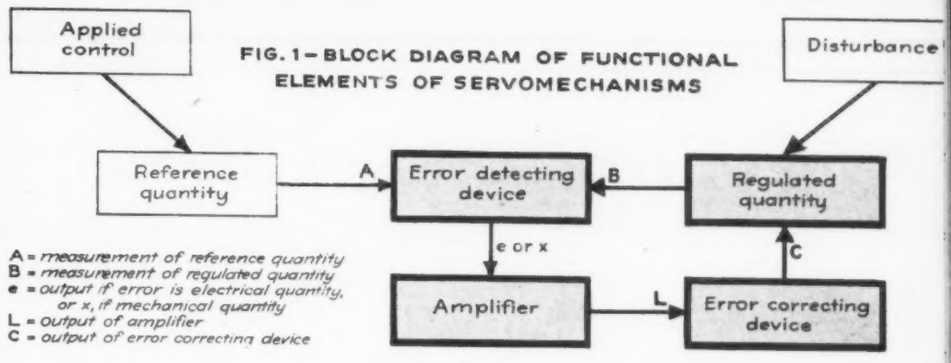
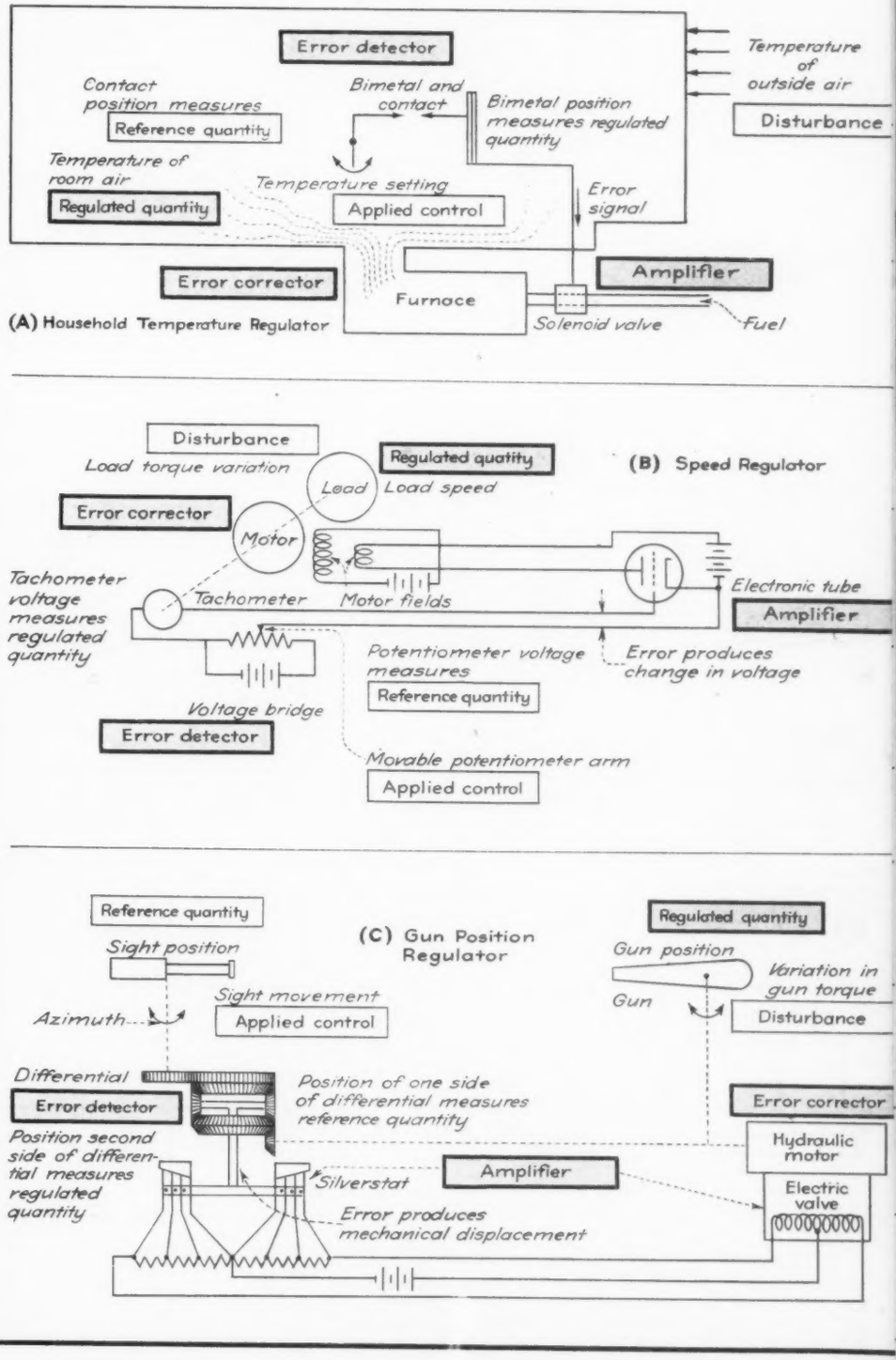
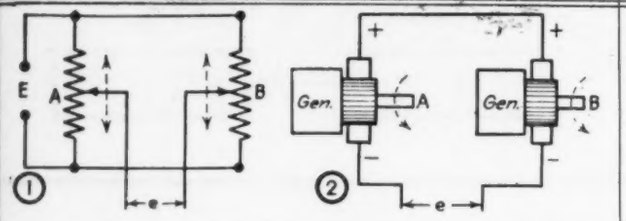



FIG. 2—TYPICAL SERVOMECHANISMS

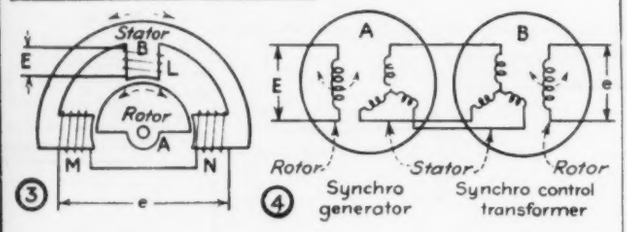


*A* = Measurement of reference quantity
*B* = Measurement of regulated quantity
*e* = Error output, electrical
*x* = Error output, mechanical

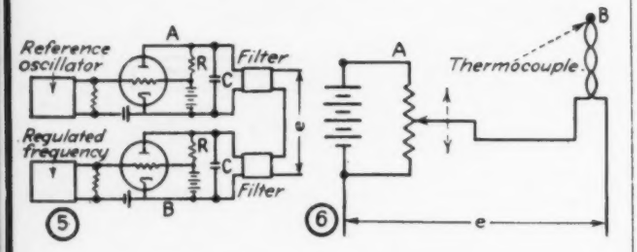
For specialized reference letters refer to description of device in Table I



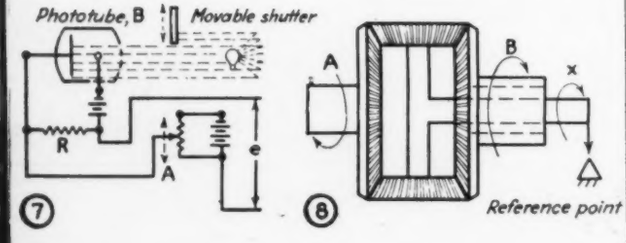

① ②



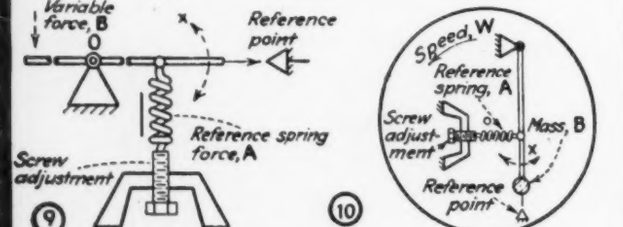

③ ④



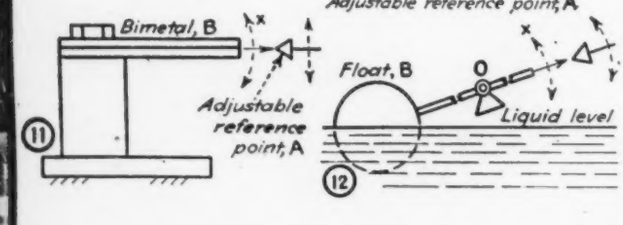

⑤ ⑥



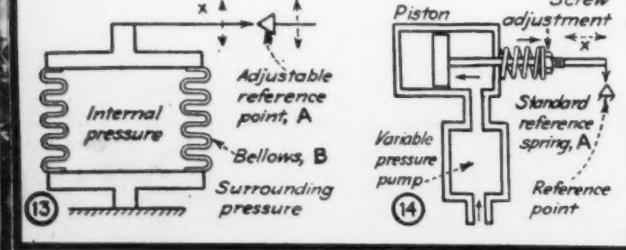

⑦ ⑧




⑨ ⑩




⑪ ⑫




⑬ ⑭

| No. | Type | Main Application | Operation |
|---|---|---|---|
| ① | D.c. or A.c. resistance bridge | Position control | Error voltage, *e*, appears whenever the position of the movi arms of the potentiometers *A* and *B* are not matched. The sa power source, *E*, is applied across both potentiometers. *A* mea ures reference position as a voltage and *B* regulated position a voltage; difference is *e*. |
| ② | D.c. tachometer bridge | Speed control | Error voltage, *e*, appears whenever the speeds of tachometers and *B* do not match. Tachometer *A* measures reference speed a voltage and *B* regulated speed as a voltage. The voltage diffe ence is *e*. |
| ③ | A.c. magnetic bridge | Position control, particularly for gyro pickups where very small forces are available | Error voltage, *e*, appears whenever the relative position rotor *A* and stator *B* is not matched. Rotor *A* measures refe ence position magnetically and stator *B* regulated position ma netically. Voltage *E*, across the exciting coil, *L*, provides th magnetic energy. When the rotor covers unequal areas of eac exposed stator pole (unbalanced magnetic bridge) the picku coils *M* and *N* have unequal voltages induced. The difference the voltages is *e*. |
| ④ | A.c. synchro-system | Position control where continuous rotation is desired | Error voltage, *e*, appears whenever the relative positions of th rotors of synchro-generator, *A*, and synchro-control transforme *B*, are not matched. The reference position is measured by *A* a magnetic flux pattern which is transmittd to the synchro control transformer through the interconnected stator winding If the rotor of *B* is not exactly 90 deg. from the transmitte flux pattern, *e* is produced. |
| ⑤ | Frequency bridge | Frequency control | Error voltage, *e*, appears whenever the reference and the reg lated frequencies are not matched. Tube channel *A* produces filtered sawtooth wave that gives a d.c. voltage inversely pr portional to the reference frequency. Tube channel *B* produce similar voltage as a measure of the regulated frequency. T difference of these d.c. voltages is *e*. |
| ⑥ | Millivolt bridge | Temperature control | Error voltage, *e*, appears whenever the regulated temperatu differs from the reference temperature. The regulated tem perature is measured as a voltage by the thermo-electric effe of two dissimilar metals, *B*. The reference temperature is repre sented as a voltage from the battery-potentiometer source *A*. T difference in these voltages is *e*. |
| ⑦ | Photo-tube bridge | Position control by intercepting a light beam | Error voltage, *e*, appears whenever the movable shutter is in position other than the desired reference position. The lig reaching phototube, *B*, is a measure of the shutter position. Th light is measured as a voltage by the phototube current vari tion with light intensity. A reference position of the shutter represented by the battery-potentiometer voltage. The diffe ence of these voltages is *e*. |
| ⑧ | Mechanical differential | Position control and speed control | Displacement *x* appears whenever the relative reference an regulated positions change. Reference position is measured as a angle by one side of the differential, *A*, and regulated positi as an angle by the other side of the differential, *B*. The diffe ence in the two positions rotates the middle member of th differential giving displacement *x*. |
| ⑨ | Beam balance | Voltage control, speed control, and tension control | Displacement *x* appears whenever the variable force is diffe ent from the reference force. The variable force, *B*, and th reference spring force, *A*, are measured as moments. The diffe ence in these moments produces displacement *x*. |
| ⑩ | Modified beam balance | Speed control, such as flyball governors | Displacement *x* appears whenever the regulated speed, *W*, dif fers from a desired reference speed. The reference speed represented by a spring force, *A*, about fulcrum, *O*. The regu lated speed is measured by the centrifugal force of the mass, *B* about *O*. The difference in the moments of these forces about produces displacement *x*. |
| ⑪ | Bimetal | Temperature control | Displacement *x* appears whenever the surrounding temperatur and the reference temperature are different. The reference tem perature is represented by the position of the adjustable refer ence point, *A*. The surrounding temperature is measured by th position of the bimetal strip, *B*. The difference in these position produces displacement *x*. |
| ⑫ | Float | Liquid level control | Displacement *x* appears whenever the regulated liquid level an the reference liquid level are different. The reference liqui level is represented as a position by the adjustable referenc point, *A*. The liquid level is measured as a position by the float *B*. The difference in these positions produces displacement *x*. |
| ⑬ | Bellows | Pressure control and temperature control | Displacement *x* appears whenever the regulated surroundin pressure and the reference pressure are different. The referenc pressure is represented as position by the adjustable referenc point, *A*. The surrounding pressure is measured by the bellow as a position. The difference in these positions produces displace ment *x*. |
| ⑭ | Piston | Pressure control | Displacement *x* appears whenever the regulated pressure outpu of the variable pressure pump and the reference pressure ar different. The reference pressure is represented as a force on th piston by the standard reference spring, *A*. The regulated pres sure is represented as a force on the piston by the fluid. Th difference in these forces produces displacement *x*. |

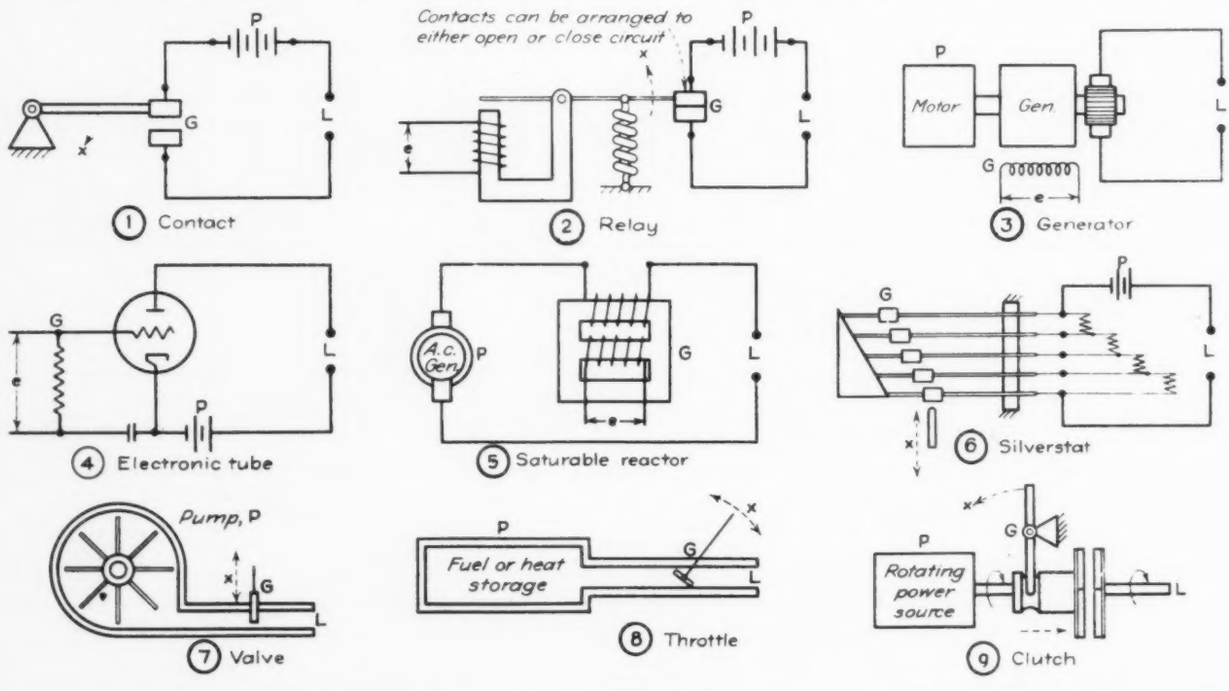
## Devices and Their Characteristics

| No. | Possible Modifications | Operating Features | Accuracy Limited By | Factors Determining Energy Required To Vary Reference Quantity Measurement $A$ | Frequently Used With This Device | |
|---|---|---|---|---|---|---|
| | | | | | No. of Amplifier in Table II | No. of Error Correcting Devic in Table III |
| 1 | Potentiometer can be wound on a helix to get more than 360 deg. of rotation. | $A$ and $B$ can be remote. Continuous rotation not possible. | Potentiometer winding. | Contact arm. Bushing friction. | 2, 3, 4, 5 | 1, 2, 3 |
| 2 | Reference $A$ can be replaced by a battery. | $A$ and $B$ can be remote. Top speed limited by commutator. | Tachometer accuracy. Commutator resistance. | Brush and bearing friction. | 2, 3, 4 | 1, 2, 3 |
| 3 | Four poles instead of three can be used with two having exciting windings and two pickup coils connected bucking. | Limited rotation. Air gap usually small. | Machining tolerance. Magnetic fringing. Voltage phase shift. | Load taken from $e$. Bearing friction. | 2, 4 | 1, 2, 3 |
| 4 | A dual system can be used whereby the unity synchrosystem sets the approximate position and the high speed, or vernier system, sets the accurate position. | Unlimited rotation. The synchro-generator and control transformer can be remote. | Machining tolerance. Accuracy of winding distribution. | Distributed or non-distributed winding of control transformer rotor. Load taken from $e$. Bearing and slip ring friction. | 2, 4 | 1, 2, 3 |
| 5 | May be used as a speed reegulator if $B$ is made an a.c. tachometer. | $A$ and $B$ can be remote. Tubes can be either gas or vacuum. A wide range of frequencies can be covered. Vacuum tubes should be used for high frequencies. | Temperature and aging effects on tube and circuit elements. | Tube input impedance. | 4 | 1, 3 |
| 6 | An electronic voltage source or another thermocouple can be substituted for $A$. | $A$ and $B$ can be remote. A wide range of temperature can be covered. | Ability to detect very low millivolt signals. | Contact arm and bushing friction. If electronic voltage source $A$ is used, tube input impedance. | 2, 4 | 1, 6 |
| 7 | An electronic voltage source or another light source and phototube can be substituted for $A$. | $A$ and $B$ can be remote. Glass surfaces through which light travels must be kept clean. | Continued accuracy of light source and phototube. | Contact arm and bushing friction. If electronic voltage source $A$ is used, tube input impedance. | 2, 4 | 1 |
| 8 | Spur gear differential. | Since $A$ and $B$ must be located together, synchroties or their equivalent can be used to transmit remote positions to $A$ and $B$. Continuous rotation possible with speed limited by gears. | Gearing backlash. | Power taken from $x$. Bearing friction. Pitch of gears. | 1, 6, 7, 8 | 1, 2, 3, 4, 5 |
| 9 | Any variable force other than a spring can be used. | For remote operation $B$ can be a transmitted force. $x$ movement limited. By changing springs a wide force range can be covered. | Load taken from $x$. Bearing Friction. | Magnitude of forces. Screw pitch and friction. | 1, 6, 7 | 1, 3, 5 |
| 10 | Any variable force other than a spring can be used. | A wide speed range can be covered. $x$ movement limited. | Load taken from $x$. Friction. | Magnitude of forces. Screw pitch and friction. | 1, 7, 8 | 1, 5 |
| 11 | Bimetal can be made snap acting at some standard temperature. | Wide temperature range possible by selection of proper bimetal. | Load taken from $x$. Ability to accurately measure small $x$ deflection. Time lag and hysteresis loop of bimetal. | Mounting of reference point. | 1, 6 | 1, 6 |
| 12 | Float controlling a pulley system can be used rather than a lever. | With the proper mechanical arrangement a wide variation in liquid height can be controlled. | Load taken from $x$. Variable density of the liquid. Friction. | Mounting of reference point. | 2, 7 | 3, 4 |
| 13 | Spring can be added in addition to bellows spring. | Limited $x$ travel. | Load taken from $x$. Hysteresis of bellows springs. | Mounting of reference point. | 1, 4, 5, 6 | 1, 6 |
| 14 | A standard pressure source can be substituted for the spring. | $A$ and $B$ can be remote. Limited $x$ travel. | Friction. Load taken from $x$. | Piston forces involved. Screw pitch and friction. | 7, 8 | 5 |

## Table II—Typical Amplifiers and Their Characteristics

| No. | Type | "Gate" Element | Input Units, Approx. | Output Units, Approx. | Power Amplification Factor, Approx. | Devices Represented by Load, *L* | Power Control |
|---|---|---|---|---|---|---|---|
| ① | Contact | Contact | Ounces | Watts | $10 \times 10^6\, t$ | Relay motor, generator field, impedance, solenoid | On-off |
| ② | Relay | Contact | Watts | Watts or kilowatts | $10 \times 10^2$ | Relay motor, generator field, impedance, solenoid | On-off |
| ③ | Generator | Field | Watts | Watts or kilowatts | 50 | Motor impedance | Continuous |
| ④ | Electronic tube | Grid | Microwatts | Watts | $10 \times 10^4$ | Relay, motor, generator field, impedance | Continuous |
| ⑤ | Saturable reactor | D.c. coil | Milliwatts | Watts | 300 | Generator field, impedance | Continuous |
| ⑥ | Silverstat | Contacts | Grams | Watts | $10 \times 10^6\, t$ | Generator field, impedance | Stepped |
| ⑦ | Valve | Valve gate | Inch-pounds | Horsepower | $10 \times 10^6\, t$ | Turret, press, heat absorption | Continuous |
| ⑧ | Throttle | Throttle valve | Inch-pounds | Horsepower | $10 \times 10^6\, t$ | Propeller, vehicle, generator, mill | Continuous |
| ⑨ | Clutch | Clutch disk | Inch-pounds | Horsepower | $50 \times 10^3\, t$ | Vehicle, mill | On-off |

*P* = Power source
*G* = Control element of amplifier
$\left.\begin{matrix} e \\ x \end{matrix}\right\}$ = Input from error detecting device
*L* = Output of amplifier, or input to error correcting device




by e if the output is electrical, and by x, if the output is mechanical.

The d.c. tachometer bridge, No. 2 in. Table I, is a typical example. Tachometer A measures the speed of a reference as a voltage. The speed of the device being regulated is measured by tachometer B as a voltage. The voltage outputs of tachometer A and B are opposed. Voltage e appears only when the speed of B is different from the speed of A. Thus a definite error indication is established.

The characteristics of an error detecting device that are of greatest importance to designers and engineers are: (1) Energy required to measure reference quantity, (2) accuracy, (3) size, and (4) reliability.

The greatest degree of design ingenuity can be exercised in the selection of an error detecting device, since many special arrangements are possible to decrease operating forces or to increase accuracy. For example, a dual synchro-system will increase accuracy. In this arrangement one synchro-system, such as No. 4 in. Table I, is geared at unity to the reference and regulated angular positions. A duplicate synchro-system is geared to the reference and regulated angular positions at some higher gear ratio which is usually odd, such as 15 or 31 to

one. When the angular discrepancy is large, the unity system takes control and through the amplifier and the error correcting device brings the angular positions into approximate agreement. At this point the vernier, or high speed system, takes over control of the amplifier and the error correcting device and precisely matches the regulated position with the reference position. The vernier system can not be used alone since it has as many matching points as its gear ratio is above unity.

The peculiar traits of mechanical, electrical, or hydraulic error detecting devices can also be used to advantage. For example, magnetic saturation can be used to obtain a particular variation of error voltage with error. Similarly, a non-linear mechanical linkage could be used.

## Amplifiers

Some typical amplifiers are shown in Table II. The broad similarity of all the amplifiers is apparent since each contains a "gate" element G that controls power flow from the power source $P$ to the load $L$. Each of these gates is a low power or small force element as compared to the power they control. For example, the contact, No. 1 in Table II, requires only ounce-inches to operate but can control many watts to the load. For high amplifications single amplifiers can be cascaded. Referring to Table II, a series composed of an electronic tube, No. 4, a relay, No. 2, and a motor operated throttle, No. 8, would provide tremendous amplification. Microwatts could control thousands of horsepower. In servomechanism applications the load $L$ taken from the final amplifier always represents the error correcting device. The difference in the power available as an error signal and power required to correct the regulated quantity determines the amplification necessary.

Many devices such as contacts, throttles, or valves have their power input determined by the time required for operation. A clutch, for example, requires inch-pounds in a certain time to control horsepower. Therefore in the amplification factor column of Table II, time factor $t$ is included. Thus the faster the clutch is operated the less its power amplification.

## Error Correcting Devices

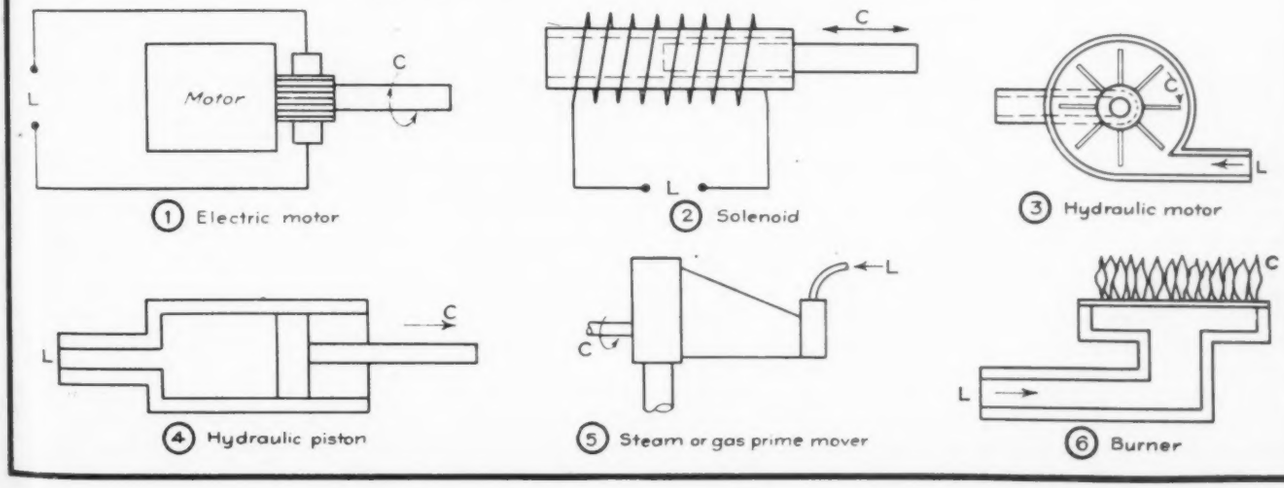
Error correcting devices including motors, engines, and pistons as shown in Table III, are probably the most familiar of the three components of a servomechanism. Every error correcting device in a servomechanism has its power input $L$ controlled by an amplifier and it in turn uses that power to correct the regulated quantity. This correction of the regulated quantity is designated by C as shown.

Many present-day servomechanism applications are the direct outgrowth of replacing an operator as an error detecting device. The automatic voltage regulator is a good example. With manual voltage regulation, the operator uses a meter to measure the regulated quantity, voltage. He detects the difference in needle position from a fixed reference position and adjusts the field rheostat to realign the needle with the reference. This procedure is carried out in exactly the same manner by the automatic voltage regulator. It balances the force of a coil that is a measure of line voltage against the force of a reference spring. When these forces are

**Table III—Typical Error Correcting Devices and Their Characteristics**

| No. | Type | Input Energy | Output Energy | Output Power Range, Approx. |
|---|---|---|---|---|
| 1 | Electric motor | Electrical | Mechanical rotation | $\frac{1}{100}$ to 40,000 hp. |
| 2 | Solenoid | Electrical | Mechanical translation | $\frac{1}{1,000}$ to 15 hp. |
| 3 | Hydraulic motor | Hydraulic | Mechanical rotation | $\frac{1}{100}$ to 110,000 hp. |
| 4 | Piston | Hydraulic | Mechanical translation | $\frac{1}{1,000}$ to 1,000 hp. |
| 5 | Steam or gas prime mover | Heat or chemical (fuel) | Mechanical rotation | 5 to 165,000 hp. |
| 6 | Burner | Chemical (fuel) | Heat | 100 to 150,000,000 B.t.u. per hour |

$L$ = Output of amplifier  $C$ = Output of error correcting device



unbalanced an error in line voltage is detected. The movement resulting from the unbalanced forces produces a change in field excitation which restores the line voltage to its correct value.

Similar comparisons can be made in the case of automatic speed governing, liquid level control, temperature regulation and many others. In all of these applications the servomechanism is more accurate and faster since the human transient response is inferior as compared to a well designed servomechanism.

### Designing a Servomechanism

The design of a servomechanism system is usually separated into the same three basic functional elements as in Fig. 1. The designer must select: (1) An error detecting device, (2) an amplifier, and (3) an error correcting device that function compatibly with each other and perform the required job.

Aside from the usual cost and reliability factors, accuracy and operating force or power determine the selection of the error detecting device. The amplifier is chosen on the basis of required amplification and time delay introduced. The error correcting device is determined by the regulated quantity and ease of coupling to the selected amplifier. Many different error-detecting, amplifier, and error-correcting combinations can be assembled to fill any servomechanism application. Quite often there is little to choose between them, and the final choice is often merely the one with which the designer has had the greatest experience.

Tables I, II and III are helpful for devising servomechanism systems. For example, suppose it is desired to regulate angular position. With relatively low accuracy, a d.c. or a.c. resistance bridge and a relay, or a mechanical differential, a contact, and a clutch could be used with an electric motor. Higher accuracy could be obtained by using an a.c. synchro-system with an electronic tube, a generator, and an electric motor; or by using an a.c. synchro-system with an electronic tube, a valve, and hydraulic motor. Each is a complete servomechanism and each has its proper place in meeting desired performance requirements. The components can be chosen from the tables. The power of the error correcting device is determined by the rate at which it is desired to vary the regulated quantity. This rate of varying the regulated quantity also determines the transient errors and to a great extent the tendency of the entire servomechanism system to "hunt."

Hunting, or self-induced oscillation of the regulated quantity without change in the reference quantity, is a problem that complicates all quick response high accuracy servomechanisms. Any closed loop system, such as shown in Fig. 1, where the output feeds back into the input has a tendency to oscillate. However, the inherent damping in the simpler servomechanisms is usually great enough to overcome this tendency and the system is stable. Where accuracy and response requirements are not too severe a servomechanism of this self-damped type will perform satisfactorily. To meet the more exact accuracy requirements, special anti-hunt circuits are used to give increased damping.

Detailed performances and stability calculations are not necessary to understand servomechanism operation. Principally, all that is required is a clear understanding of Fig. 1. The interrelations shown of the reference quantity, error detecting device, amplifier, error correcting device, and regulated quantity, provide the basis of all servomechanism. From combinations of items in Tables I, II and III a large number of servomechanisms can be devised. With future requirements greatly increased for high accuracy, fast response, remote operation, and unattended control it is expected that many more servomechanism applications will be made.

# Case Histories In Patent Law

H. A. TOULMIN, JR.

[EDITOR'S NOTE: These explanations of the law in specific patent cases are not intended to supplant the services of a patent attorney, whose accurate advice is necessary to handle individual patent problems. The purpose of these explanations is to give a better general understanding of patent law.]

NO. 2

QUESTION: Can a patent be declared invalid because it is indefinite?

ANSWER: One of the principal grounds of modern courts in arriving at a decision to invalidate the patent has been the indefiniteness of the claims. It is only a matter of good faith that a patentee should define the property which has been granted to him as a monopoly with clear and precise terms. If you are receiving a piece of property by grant through a real estate deed, you would be very careful to see that the grantor defined by metes and bounds and by well defined distances the property you were to buy. And so it is with a patent.

The Supreme Court said recently in United Carbon Co. vs. Binney & Smith Co., 317 U. S. 228, an invention must be capable of accurate definition and if it is capable of accurate definition it must be accurately defined to be patentable. In other words there are two tests: First, anything that cannot be accurately defined is not an invention that is patentable and anything that is not accurately defined does not become a good patent. For instance, a patentee may not broaden his claims by describing his product in terms of the things it does, that is, in terms of function.

A claim which said "Substantially pure carbon black in the form of commercially uniform, comparatively small, rounded, smooth aggregates having a spongy or porous interior" was held by the Supreme Court to be invalid both because it was indefinite and because it attempted to define an article in terms of function.

As the Supreme Court said, "The claims are but inaccurate suggestions of the functions of the product, and fall afoul of the rule that a patentee may not broaden his claims by describing the product in terms of function."

The use of words such as "substantially," "commercially uniform," "Comparatively small," and similar comparative but indefinite terms creates fatal defects in the claims.

Because obviously it is important to know exactly what the patentee claims so that a man may honestly avoid taking this property. Equal candor is necessary on the part of the patentee to define what he thinks is his property. For instance in one case the patent claims called for a radiator lighter than cast iron but at the trial it was demonstrated that certain cast iron radiators were lighter than the copper radiator which the claim sought to cover by this indefinite terminology. The patent was defeated.

Likewise in the balloon tire case, balloon tires were defined by relative terms as to size. The court held that the patent covering the balloon tires was invalid because it was based upon a comparative set of terms which had no definite limitations as to where the limits started and where they stopped.

# Design of Groove-Form Screws With Ball-Bearing Nuts

**VLADIMIR L. MALEEV**
Research Engineer, Harvey Machine Company, Inc.

**Consecutive steps in the design of power screws with ball-bearing nuts. Equations are given for determining the column stiffness of screw, lead of the screw based on strength of thread, length of nut based on permissible deviation of the free end of the screw, and allowable normal load on the balls by means of Hertzian constants.**

LOADS of tens of tons are not uncommon on the power screws used rather extensively for aircraft control. In power screws with ball-bearing nuts, hard polished steel balls roll between the threads of the screw and those of the nut thus introducing rolling friction in place of sliding friction found in the conventional screw and nut.

Loss of work caused by friction is undesirable in any power screw and becomes particularly objectionable when the power transmitted is large. If $\lambda$ is the helix angle and $f$ is the friction coefficient, the efficiency $\eta$ of an ordinary screw and nut with a rectangular thread is

$$\eta = \tan \lambda \, (1 - f \tan \lambda)/(\tan \lambda + f) \qquad (1)$$

In standard single-thread screws, $\lambda$ ranges from about 7 deg. for 1/4 in. dia. screws to 3 deg. for 4 in. dia. screws. The sliding friction coefficient $f$ usually lies between 0.10 and 0.15 and at best is not less than 0.05. With these values substituted in Equation (1) $\eta$ ranges from 71 to 26 percent.

By introducing rolling friction in place of sliding friction, the efficiency is improved. The coefficient of friction between hardened steel balls and races ranges from 0.0003 to 0.0015. (Rosenfeld, L., "Friction of Ball and Roller Bearings," *Engineering* (London), September 29, 1944, p. 257.) Equation (1) gives a theoretical efficiency of 97.2 percent for the extremely unfavorable values of $f$ equal to 0.0015 and $\lambda$ equal to 3 degrees.

A typical screw with ball nut is shown in Fig. 1. The thread grooves have a semi-circular cross-section; the nut has a circuit of either 1½ or 2½ rows of active balls and a return tube that forms a closed course in which the inactive balls roll. If more than 2½ rows are used in one circuit, the resistance to circulation of the balls increases excessively, thus lowering the efficiency because of a decrease of fluidity in the circuit. Measured efficiencies of screws with ball nuts are 90 percent and higher. Ordinarily two circuits with a long nut, Fig. 2, are used to obtain a small deflection of the screw center line. The nut length $L_n$, Fig. 2, is the distance between the centers of the first active ball in the first circuit and of the last ball in the last circuit.

To avoid sliding friction between the screw and nut, the outside diameter $D_s$ of the screw is made 1.0 to 1.5 percent smaller than the ball-circle diameter $D_c$. The diameter $D_c$ corresponds to the pitch diameter of an ordinary screw.

The life of a nut is influenced by the number of passages or passes of one ball under load over one particular spot on the ball race per revolution of screw. The number of passes depends upon whether the nut or the screw turns. If the nut turns one revolution, the actual rotation of each ball about the center of the stationary screw will be slightly more than if the screw turns one revolution while the nut is stationary. The life of the nut is influenced in proportion.

The following design procedure is based

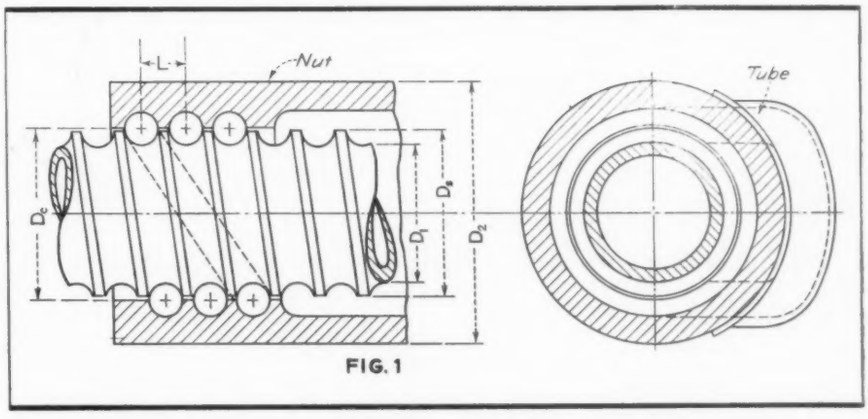



Fig. 1—Power screw with ball nut having a circuit of a 2½ rows.

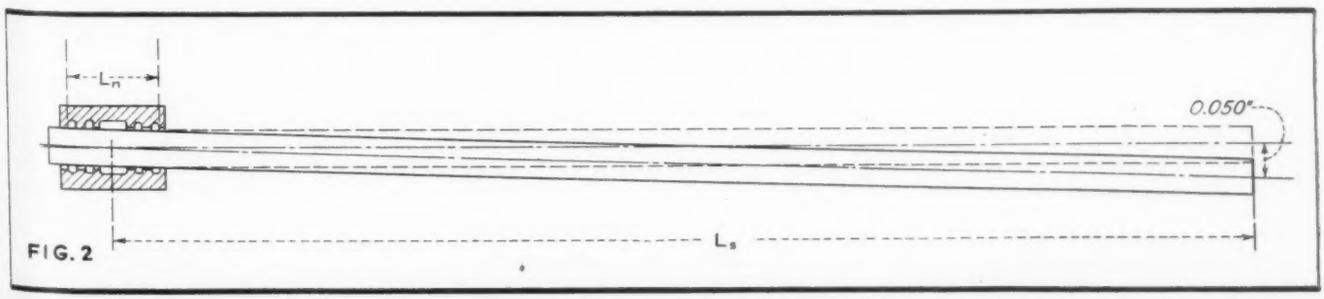



Fig. 2—Deviation of center line of screw from center line of nut that results from thread clearance between nut and screw.

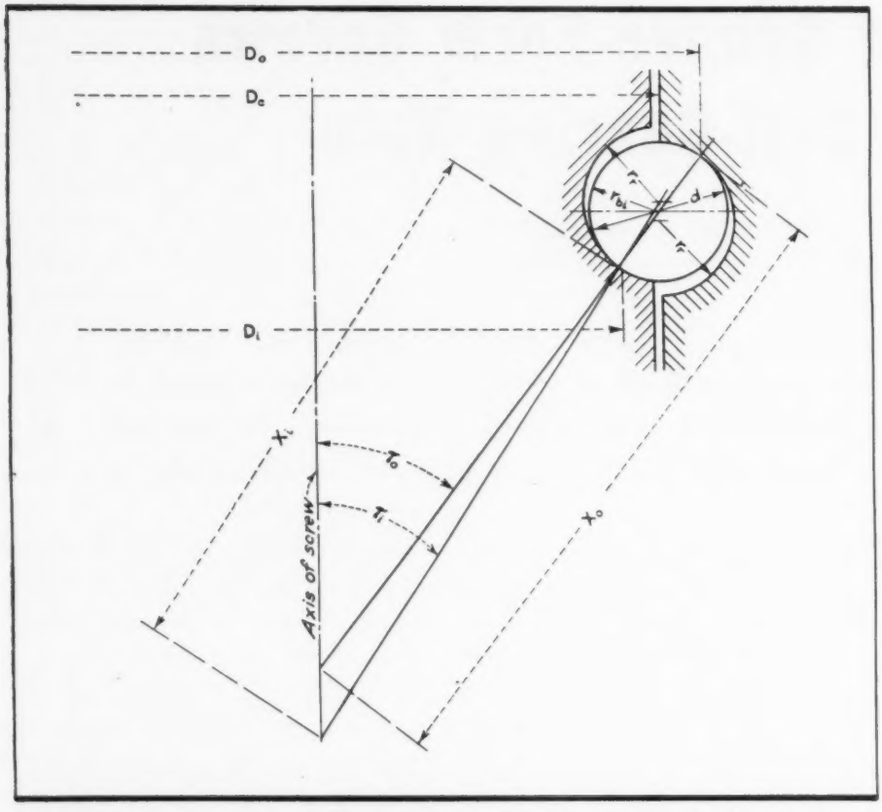



**Fig. 3—Increased race radius affects normal angles at points of contact.**

on a ball-race hardness of Rockwell C60 to C63, obtained through a deep carburizing and hardening of low-carbon alloy steels such as SAE 5120 and 4620. The allowable bearing stress can be as high as 550,000 lb. per sq. in., but lower stresses should be used if long life is desired.

ROOT DIAMETER. The screw is made hollow to save weight. The outside diameter $D_i$ of the hollow column can be found by Ritter's formula:

Where $F$ = outside load, lb.
$A$ = area of the cross-section of the O. D. of screw, sq. in.
$S_c$ = allowable compressive stress, lb. per sq. in.
$L_s$ = length of column, Fig. 2, in.
$k$ = radius of gyration of screw section
$S_e$ = elastic limit of screw material, lb. per sq. in.
$n$ = coefficient of end conditions of column
$E$ = modulus of elasticity of screw material, lb. per sq. in.

$$F = \frac{AS_c}{1 + \left(\frac{L_s}{k}\right)^2 \frac{S_c}{\pi^2 n E}} \qquad (2)$$

The end of the column in the nut can be considered clamped and the other end either free as in a jack screw, when $n$ equals 0.25, or guided as in an actuator, when $n$ equals 2.

BALL SIZE selected depends upon:

(a) Number of active balls in a circuit; (b) lead of the screw, for a single-thread screw the lead is equal to its pitch $p$; and (c) nut length $L_n$. Ball sizes used in present design range from 1/16 to 3/4 in. as given in Table 1, which may serve as a general guide for the preliminary design.

BALL-CIRCLE DIAMETER. If $d$ is the ball diameter, and $D_i$ is root diameter of groove in screw, the ball circle diameter $D_c$ is

$$D_c = D_i + d \qquad (3)$$

NUMBER OF BALLS. If $t$ is the number of turns in a circuit, 1½ or 2½, depending upon the load and size of balls, the number of active or load carrying balls $B$ in a circuit is

$$B = \pi D_c t/d \qquad (4)$$

If $B$ is found to be greater than 60 balls, the size of balls must be increased, irrespective of the load capacity, until $B$ is equal to or less than 60, to maintain a sufficient fluidity.

LEAD. In most designs it is desirable to use as small a lead $L$ as possible since the helix angle does not affect noticeably the efficiency of this type of screw. A small lead reduces the torque and for a given power input permits a high speed, hence a small gear reduction between motor and screw. The minimum lead may be about 1/32 in. greater than the ball diameter $d$. Table I gives the relation between $L$ and $d$, as used in practice.

NUT LENGTH. Experience shows that it is desirable to have 0.003 in. diametral clearance between the screw and nut. In most designs a maximum displacement of 0.050 in. of the end of the center line of the screw from the axis of the nut, Fig. 2, is permissible. Then, from the similar triangles

$$L_n = 0.06\, L_s \qquad (5)$$

Usually the nut contains two circuits. By spreading the circuits apart with a relieved section between, any desired length $L_n$ can be obtained. With two or more circuits, it is advisable to turn one 180 deg. to the other to obtain a uniform play that does not exist when the return tubes are on one side of the nut.

If $p$ is the pitch, the actual overall length $L_s$ of the nut will be greater than or at least equal to

$$L_s = L_n + 2p - d \qquad (6)$$

RACE RADIUS. The radius $r_r$ of the helical grooves, both in the screw and in the nut, is made larger than the radius of the balls to reduce sliding friction. For small balls having a diameter $d$ equal to or less than 5/32 in., this radius is

$$r_r = 0.5d + 0.009, \text{ in.} \qquad (7)$$

for balls having a diameter $d$ equal to or greater than 3/16 in. the radius is

$$r_r = 0.55d \qquad (8)$$

ANGLE OF NORMAL TO POINT OF CONTACT. When the radius $r_r$ of the helical grooves is greater than 0.5$d$, under an axial load the normals to the points of contact between a ball and the inner and outer races will form slightly different angles $\tau_i$ and $\tau_o$ respectively, with the axis of the screw, Fig. 3. The angles will also be less than 45 degrees.

Where $r_{b1}$ = radius of the ball when not stressed
$r_{b2}$ = radius of the ball compressed
$X_i$ = normal distance from the point of inner contact to the axis
$X_o$ = normal distance from the point of outer contact to the axis

The cosine of angle $\tau_i$ for the inner race is

$$\cos\tau_i = \frac{1/r_{b1} - 1/r_{b2} + 1/X_i + 1/r_r}{1/r_{b1} + 1/r_{b2} + 1/X_i - 1/r_r} \qquad (9)$$

and the cosine of angle $\tau_o$ for the outer race is

$$\cos\tau_o = \frac{1/r_{b1} - 1/r_{b2} - 1/X_o + 1/r_r}{1/r_{b1} + 1/r_{b2} - 1/X_o - 1/r_r} \qquad (10)$$

For all practical purposes $r_{b1}$ equals $r_{b2}$, which simplifies Equations (9) and (10).

Evidently from Fig. 3,

$$X_i = 0.5\left(\frac{D_c}{\sin\tau_i} - d\right) \qquad (11)$$

$$X_o = 0.5\left(\frac{D_c}{\sin\tau_o} + d\right) \qquad (12)$$

Accurate values of $X_i$ and $X_o$ can be computed only after the angles $\tau_i$ and $\tau_o$ have been found. However, the error in the values of $X_i$ and $X_o$ will be very small if they are found by Equations (9) and (10) taking $X_i$ and $X_o$ at first either for $\tau$ equal to 45 deg. for an expected smaller angle.

ALLOWABLE NON-BRINELL LOAD. The design is such that the inner race has the

smaller area of contact, so that the allowable non-Brinell load is found by multiplying the elliptical area of contact of the inner race by the allowable compressive stress.

Where $F$ = normal load per ball
$M$ and $V$ = Hertzian constants (See Fig. 4) for particular values of cos$\tau$

the elliptical area of contact of the inner race is equal to $\pi ab$, where $a$ is one half the major axis and $b$ is one half the minor axis of the ellipse,

$$a = 0.00446\, M \times \sqrt[3]{F/(2/r_{bi} \pm 1/X_i - 1/r_r)} \quad (13)$$

the plus sign before the term $1/X_i$ is used for the inner race and the minus sign for the outer one.

$$b = aV/M \quad (14)$$

With an allowable average bearing stress $S_b$, the allowable normal load $F$ per ball is

$$F = \pi abS_b \quad (15)$$

With $B$ active balls the corresponding total allowable axial load is

$$F_a = BF\cos\tau_o \quad (16)$$

The maximum static load must be smaller than $F_a$ to avoid brinelling.

**Table 1—Design Data for Ball-Nut Screws**

Courtesy Saginaw Steering Gear Division, General Motors Corporation

Max. load per row is based on a life of $5 \times 10^6$ revolutions.

| Ball Circle Dia. $D_c$, in. | Small-Ball Series | | | | Medium-Ball Series | | | | Large-Ball Series | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ball Dia. $d$, in. | Min. Lead $L$, in. | Nut O.D. $D_2$, in. | Max. Load per Row $F$, lb. | Ball Dia. $d$, in. | Min. Lead $L$, in. | Nut O.D. $D_2$, in. | Max. Load per Row $F$, lb. | Ball Dia. $d$, in. | Min. Lead $L$, in. | Nut O.D. $D_2$, in. | Max. Load per Row $F$, lb. |
| 0.4 | 1/16 | 0.125 | 0.57 | 100 | 5/64 | 0.140 | 0.61 | 140 | 3/32 | 0.163 | 0.65 | 210 |
| 0.6 | 5/64 | 0.140 | 0.81 | 180 | 3/32 | 0.163 | 0.85 | 265 | 7/64 | 0.187 | 0.89 | 365 |
| 0.8 | 3/32 | 0.163 | 1.05 | 320 | 7/64 | 0.187 | 1.08 | 450 | 1/8 | 0.208 | 1.13 | 560 |
| 1.0 | 7/64 | 0.187 | 1.29 | 500 | 1/8 | 0.208 | 1.33 | 645 | 5/32 | 0.245 | 1.41 | 1,010 |
| 1.2 | 1/8 | 0.208 | 1.53 | 720 | 5/32 | 0.245 | 1.61 | 1,140 | 3/16 | 0.281 | 1.69 | 1,550 |
| 1.4 | 9/64 | 0.225 | 1.77 | 1,000 | 3/16 | 0.281 | 1.89 | 1,700 | 1/4 | 0.343 | 2.05 | 2,535 |
| 1.6 | 3/32 | 0.245 | 2.01 | 1,360 | 7/32 | 0.313 | 2.17 | 2,070 | 5/16 | 0.406 | 2.42 | 3,780 |
| 2.0 | 3/16 | 0.281 | 2.49 | 2,120 | 1/4 | 0.343 | 2.65 | 3,150 | 3/8 | 0.500 | 2.98 | 4,360 |
| 3.0 | 1/4 | 0.343 | 3.65 | 4,065 | 5/16 | 0.406 | 3.82 | 5,540 | 1/2 | 0.660 | 4.30 | 8,520 |
| 4.5 | 3/8 | 0.500 | 5.48 | 8,130 | 7/16 | 0.568 | 5.64 | 10,700 | 5/8 | 0.845 | 6.13 | 15,200 |
| 6.0 | 1/2 | 0.660 | 7.30 | 14,080 | 5/8 | 0.845 | 7.63 | 19,100 | 3/4 | 1.000 | 7.95 | 23,900 |

Stress at Point of Contact. The life of the nut with its shorter length is lower than that of the longer screw. Therefore, the stress calculation must be made for the outer race.

The normal load $F_n$ per ball produced by the operating load $F_1$ is

$$F_n = F_i/B\cos\tau_n \quad (17)$$

Then the average normal bearing stress is

$$s_{ba} = F_n/\pi ab \quad (18)$$

The maximum stress is 1.5 times greater, or

$$s_b = 1.5F_n/\pi ab \quad (19)$$

Number of Passes per Cycle. The number of passes per revolution of the nut or screw is equal to the fraction of revolution of a ball about the axis of the screw times the number of balls per turn. The number of revolutions that the balls will make about the axis of the screw for each revolution of the nut can be found as follows: The contact diameters of the balls are, from Fig. 3, for the outer race

$$D_o = D_c + d\sin\tau_o \quad (20)$$

and for the inner race

$$D_i = D_c - d\sin\tau_i \quad (21)$$

Considering the ball and races as a planetary unit gives the number of revolutions $n_b$ of the ball about the axis of the screw per revolution of the nut

$$n_b = D_o/(D_o + D_i) \quad (22)$$

and the nut will turn one revolution in the same direction while the balls are turning $n_b$ revolutions. The relative motion $n_r$ between the balls and nut therefore is

$$n_r = 1 - n_b \quad (23)$$

Substituting Equation (22) in Equation (23) the relative rotation $n_r$ is

$$n_r = D_i/(D_o + D_i) \quad (24)$$

With a lead $L$, the number of revolutions $n_n$ of the nut for one complete cycle, that is, for one stroke $u$ forward and one return, is

$$n_n = 2\,u/L \quad (25)$$

and the number of passes each ball will make over a particular spot in the nut will be $n_r$ times $n_n$. With the designations as used in Equation (4), the number of balls in one row is $B/t$ and therefore the number of passes $n_p$ per cycle will be

$$n_p = n_r n_n B/t = 2D_i\,u\,B/[(D_o + D_i)Lt] \quad (26)$$

Allowable number of passes $N_p$ is a function of the maximum bearing stress $s_b$ and is

$$N_p = 996 \times 10^{56}/(s_b)^9 \quad (27)$$

For convenience $N_p$ can be taken directly from the curve of Fig. 5, which is plotted for a range of maximum bearing stress values.

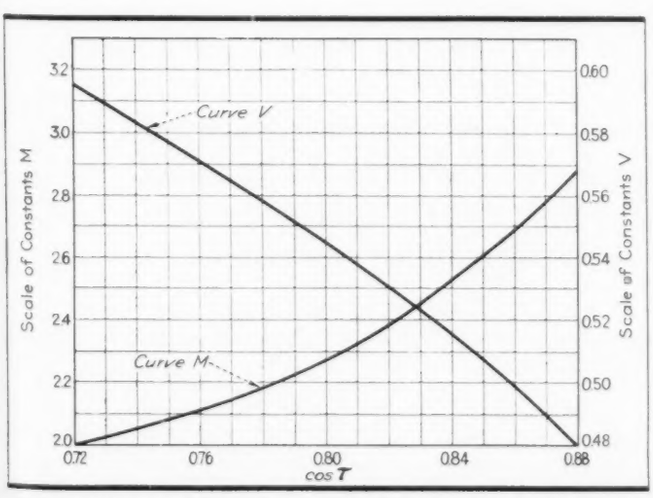



**Fig. 4—Values of Hertzian constants for cosines of different normal angles.**

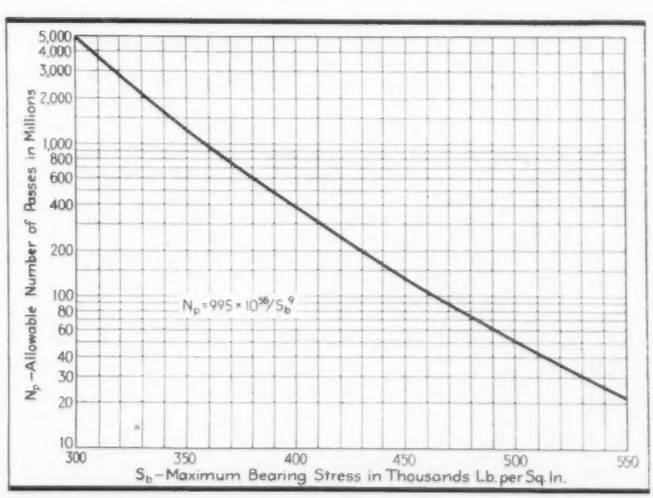



**Fig. 5—Allowable number of passes as a function of maximum bearing stress.**

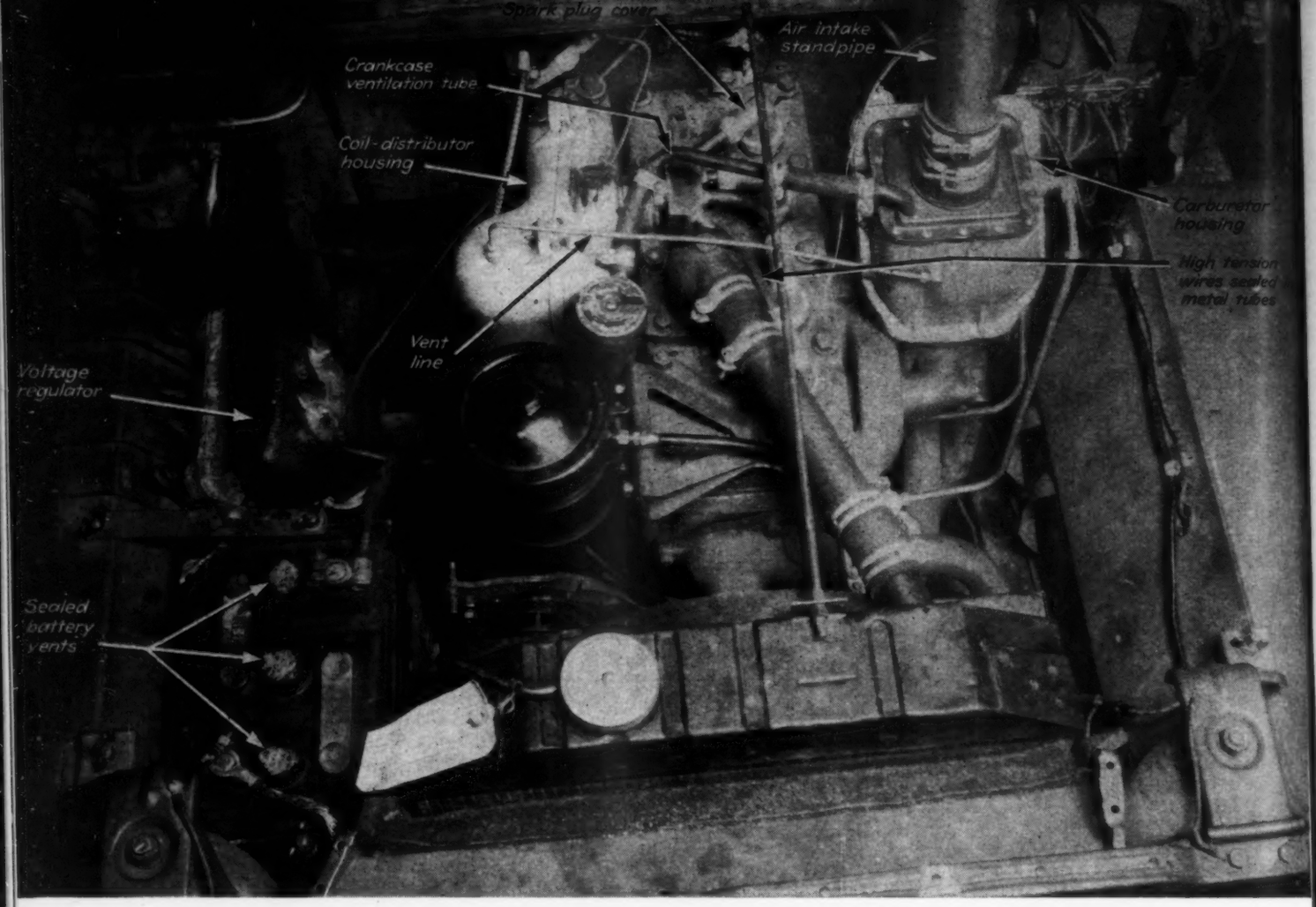



**Fig. 1—Engine and electrical parts as they were prepared for the preliminary underwater test.**

# Design and Sealing Problems For Underwater Operation of a Vehicle

**D. D. STONE**
Director of Research, Willys-Overland Motors, Inc.

**Problems that were solved to allow a Jeep to operate in six feet of water are described. Many of the individual problems, and their step by step solutions, are discussed to indicate the methods of sealing that were tested during the development program and before the final design was completed.**

OPERATION of a Jeep for fifteen minutes in six feet of water was one of the wartime design problems proposed by the Army Ordnance Department to Willys-Overland engineers. The Navy Department also became interested in this development and it therefore was carried on as a joint project. The request required that a Jeep be made to operate under these conditions and that a kit must be designed to adapt any Jeep to this service when required in the various theaters of war.

The development program was based on the results of a preliminary test, requested by Army Ordnance, in which a Jeep had been operated for 45 min. completely submerged in water.

Preparation for this preliminary test was divided into the following design problems:

1. The air intake and exhaust system
2. Air vents
3. Electric system—including suppression
4. Sealing the engine against water

The air intake system required that the carburetor be sealed and a standpipe extended above the 6 ft. water depth. The

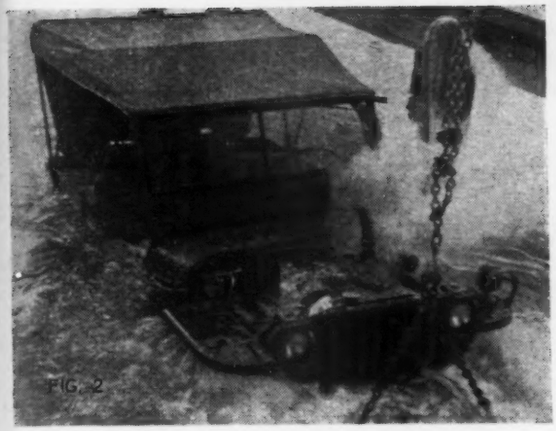


**Fig. 2—Jeep entering the water in the preliminary test to completely submerge the vehicle for the 45 min. of underwater operation.**

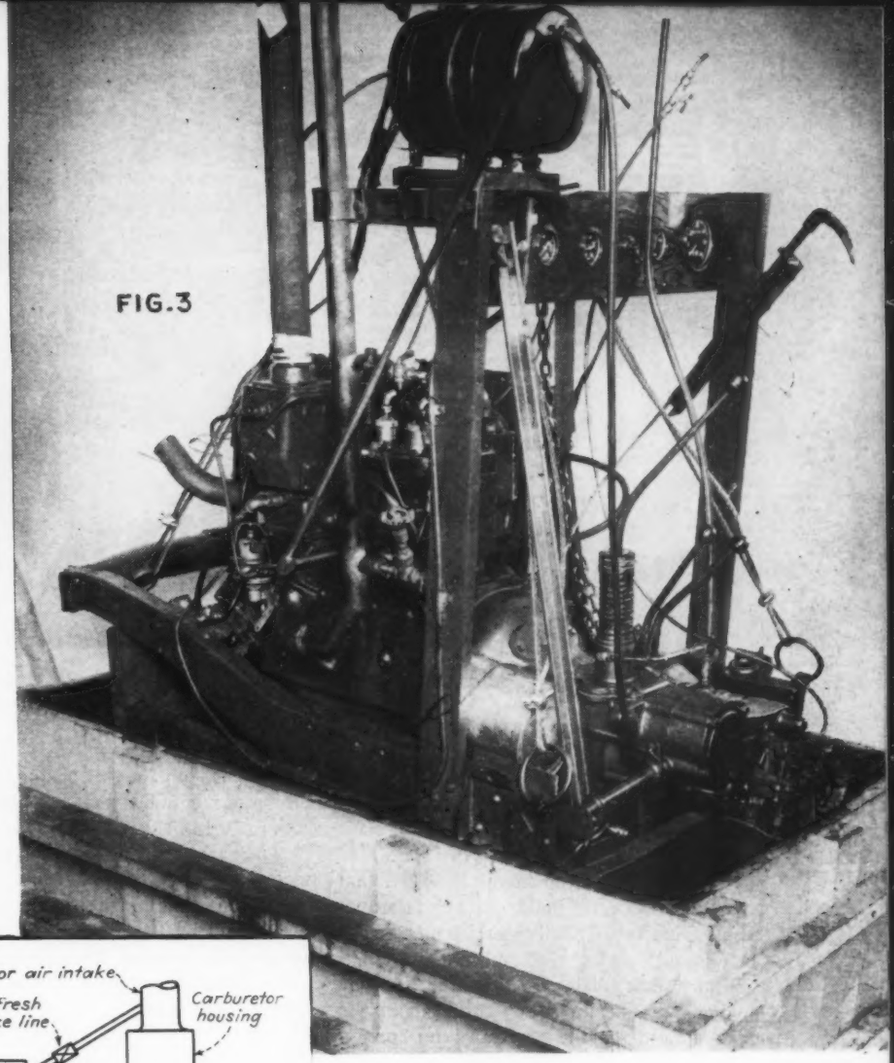
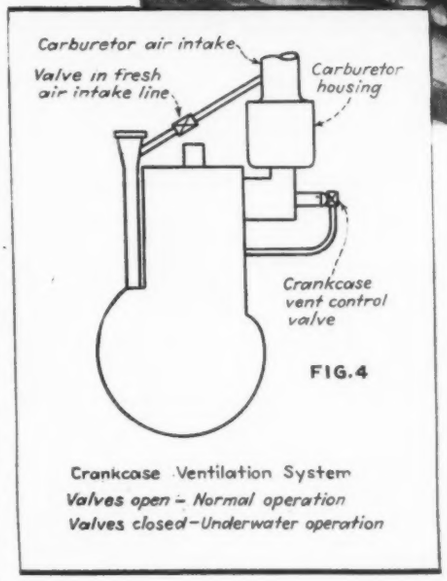


**Fig. 3—Test tank used for the solution of the many sealing problems that had to be solved before a satisfactory design could be developed.**

**Fig. 4—Method of using piston blow-by to develop sufficient internal pressure to prevent water from entering the crankcase.**




exhaust system required a similar standpipe arrangement with all joints sealed against the penetration of water.

The carburetor was sealed in an aluminum housing, shown in Fig. 1, to which the standpipe was attached. Sealing of this housing to the manifold required careful gasketing. The entry of the throttle shaft was sealed with a standard leather seal designed for use on a shaft of 3/8 in. diameter.

Air vents were required for crankcase ventilation, the gasoline tank, and the transmission and transfer cases. The crankcase ventilation air vent was extended from the oil filler pipe over to the carburetor housing. A small vent line was also run between the coil-distributor and the carburetor housings. The gasoline tank cap was sealed and a vent pipe was run to the top of the windshield. The breather hole in the tower of the transmission was sealed, by a rubber boot, and a breather pipe was run to the top of the windshield.

The ignition system required waterproofing of all parts but for the purpose of this preliminary test no changes were made in the generator or the starting motor. The distributor and ignition coil were placed in an aluminum housing similar to the carburetor housing. Spark plugs were sealed by aluminum covers surrounding each spark plug. All high tension wiring was housed in metal tubing extending from the distributor-coil housing to the individual spark plug covers. The battery vents were sealed and the voltage regulator was made waterproof. Glyptal Sealer No. 1201 manufactured by the General Electric Company was applied to all electrical connections to protect them against electrolysis. Since this was a preliminary test to prove only that underwater operation was possible few, if any, special seals were used on the engine and its accessories.

The preliminary test was made in a small boat launching shed and the Jeep was lowered in deep water and immersed, as shown in Fig. 2, to the required depth. The engine was running with the transmission in high gear, transfer case in lower gear, 4-wheel drive and the throttle adjusted, while the vehicle was suspended in the air, to a speedometer reading of 40 m.p.h. When the Jeep was immersed the speedometer registered 18 m.p.h. Operation of the Jeep under these conditions was continued for 45 min., when the vehicle was removed from the water and driven about 1/10 mi. to determine if all parts and components involved operated satisfactorily.

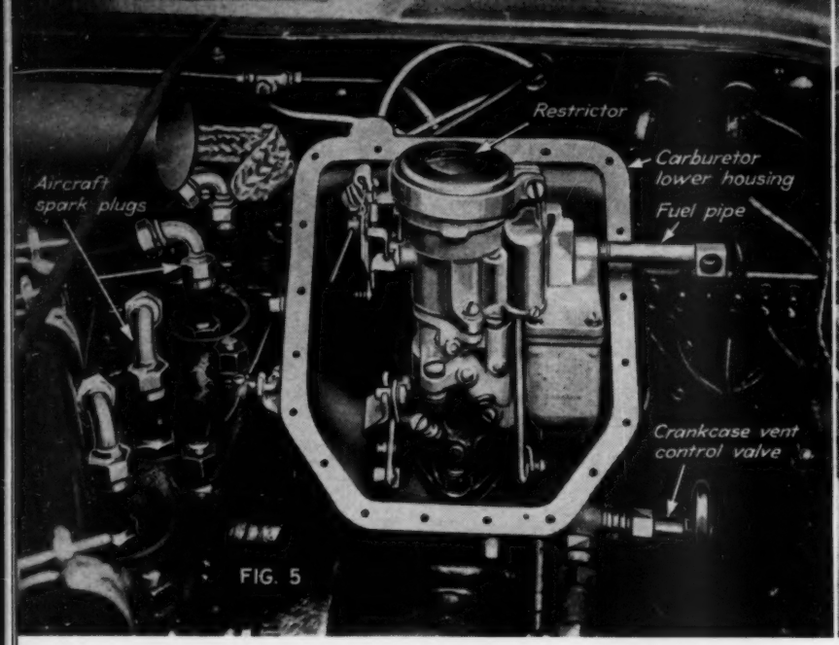
Examination of vehicle showed that the principal difficulty was water in the lubricants. The percentage of water in the various lubricants was as follows:

| | |
|---|---|
| Engine crankcase | 73% |
| Left front axle ball joint | 24% |
| Right front axle ball joint | 23% |
| Transmission | 18% |
| Transfer case | 14% |
| Rear differential | 11% |
| Front differential | 7% |

The large percentage of water in the engine crankcase resulted in the most serious difficulty as the oil-water mixture formed an emulsion that traveled up the oil filter tube and found its way, through the breather vent pipe, into the carburetor housing.

The generator was the only part of the electrical system that was not satisfactory, since the spacers in the armature slots had swelled and were binding on the field poles. The starter was rusted but functioned satisfactorily.

The difficulties of working on the engine, when installed in a Jeep led to further testing of the engine in a tank set-up in the laboratory, shown in Fig. 3. The preliminary tests had shown that the ignition system



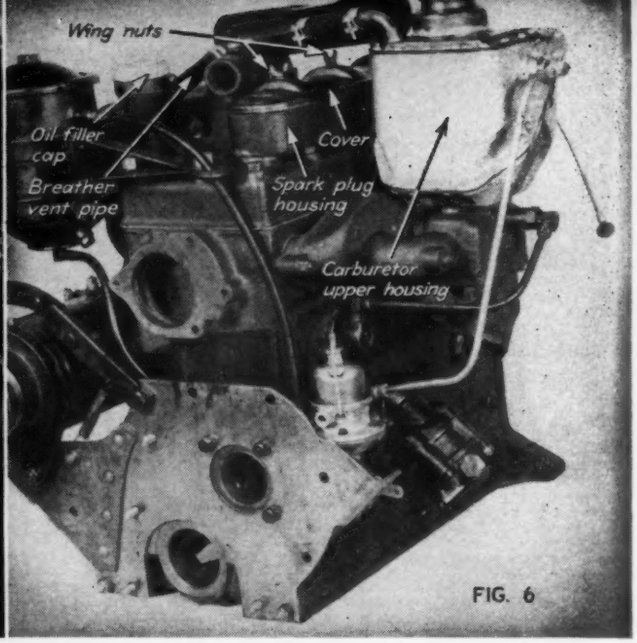




**Fig. 5—Carburetor required a restrictor to give the pressure differential, necessary for operation, between its interior and surrounding air. Fig. 6—Spark plugs housed in a water-tight housing; removable cover proved difficult to seal.**

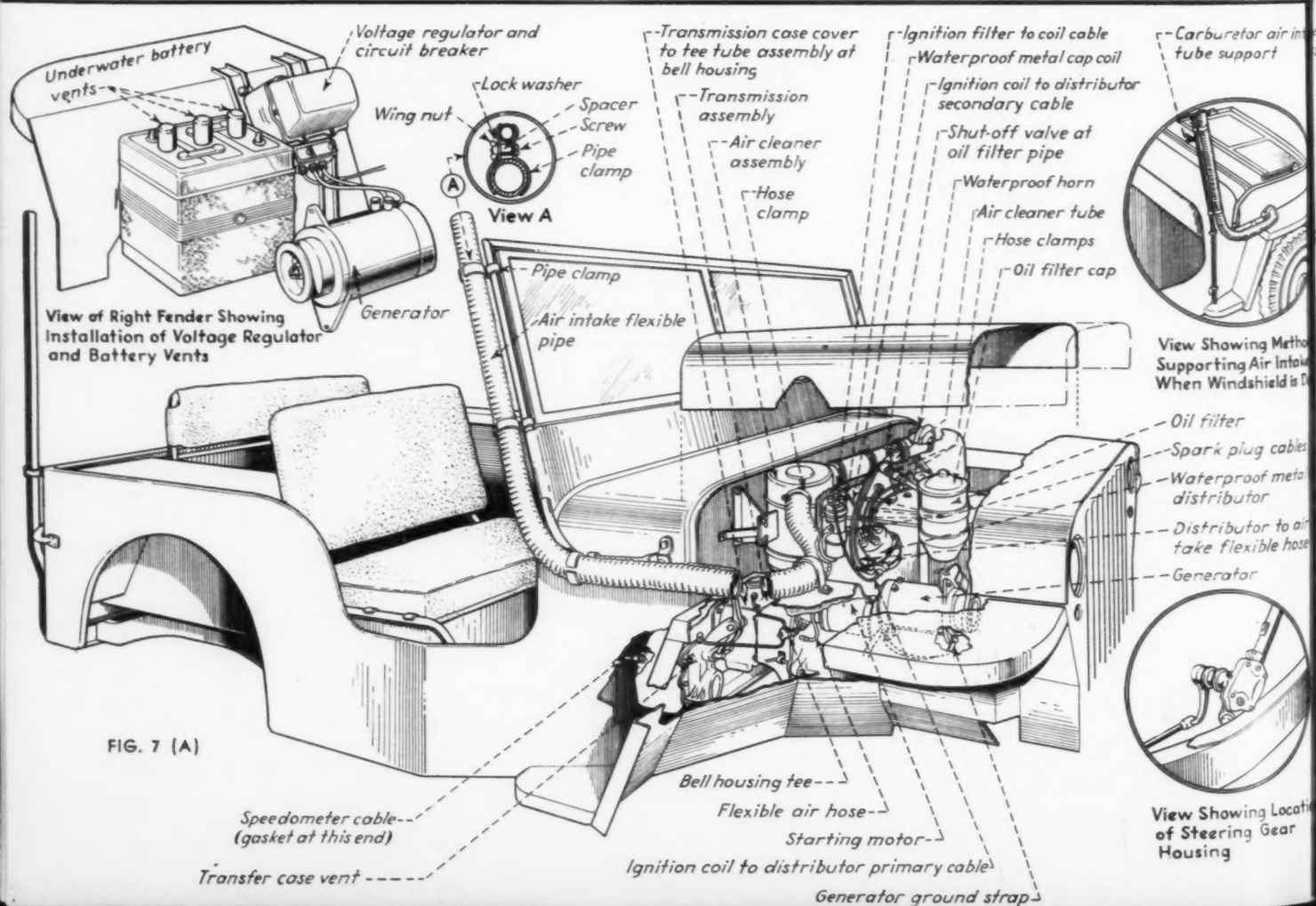
was too difficult to service or manufacture. Water must be prevented from entering the engine crankcase and changes had to be made in the gasoline tank vent and cap seal.

Further tests of the engine indicated that it was possible to build up a pressure of approximately 1 1/2 lb. per sq. in. in the crankcase by sealing the crankcase ventilation and air intake tubes and permitting blow-by to build up the pressure. Tests run in the tank showed that little or no water entered the crankcase when this pressure was maintained. To obtain this crankcase pressure a leak-proof oil filler cap and two valves, as shown in Fig. 4, were required.

The carburetor housing was redesigned to reduce the number of gaskets and all holes were blind tapped to prevent leakage past the threads. The housing was fitted with a drain plug so that any water that might enter could be removed. It was necessary to place a restrictor, Fig. 5, in the top of the carburetor, since the carburetor must operate with a slight pressure differential between its interior and the surrounding air.

A waterproof ignition system presented the most difficult design problem. Since the original design was satisfactory in tests, but was difficult to service and manufacture, a box type of housing, having a cover held in place by three wing nuts, Fig. 6, was designed but proved unsatisfactory.

The use of the conventional automotive ignition system components had so complicated the design that a new approach to the design problem was needed. It was, thus



necessary to design a distributor and an ignition coil that were waterproofed, and to use aviation type spark plugs. The primary wires leading to the distributor, as well as the high tension wires between the distributor, the ignition coil and the spark plugs were attached through water-tight connectors. The electrical installation was then checked to assure proper suppression against radio interference.

Other electrical items had to be waterproofed. The battery was equipped with specially vented caps. The starter and the generator were made water resistant by painting the armature and field coil insulation with a waterproof varnish. Other parts, including the Bendix starter pinion assembly were cadmium plated to make them rust resistant. The electrical instruments, including voltage regulator, ignition switch, and starter switch, and also the speedometer were all made waterproof in construction.

All air inlet connections were made with rubber hose, as shown in Fig. 7. A waterproof oil bath type air cleaner was developed having special seals for the oil pan to eliminate any chance of leakage. The air intake was connected with a rubber hose that extended under the right side of the hood and was attached to the windshield post and projected above the water line.

The transmission required a waterproof boot at the shifter column and a heavy gasket shellacked in place under the transmission cover. The transmission and transfer case were vented through a tube connecting the air inlet tube to the oil bath air cleaner. The gasoline tank was vented through a special tube connected to the air cleaner inlet tube through a flexible rubber tube. A special gasoline tank cap, having a two-way pressure valve, permitted either a build-up of approximately 2 lb. pressure or approximately 1/2 lb. vacuum in the gasoline tank before opening. The cap was designed so that venting of the valve was done only through the connection to the vent tube.

To keep water out of the steering gear and also the front axle universal joint housings, these parts were filled with a water repellent lubricant. For the steering gear, Lubriplate No. 50 was used and the regular water repellent chassis lubricant, specified by the Army under their specification No. 2-106, was used in the axle universal joint housings.

Field tests were made at a nearby beach where the vehicle was driven into the water after closing the crankcase ventilation valves. It was operated as shown in Fig. 8, for the required 15 min. and inspected with no indication of leaks. The Jeep was then driven for 30 min., in 5 ft. of water, and steered well and at no time showed any tendency to sink or bog down in the sand. Later inspection showed that the early difficulties had been overcome and that operation under these severe conditions was satisfactory.

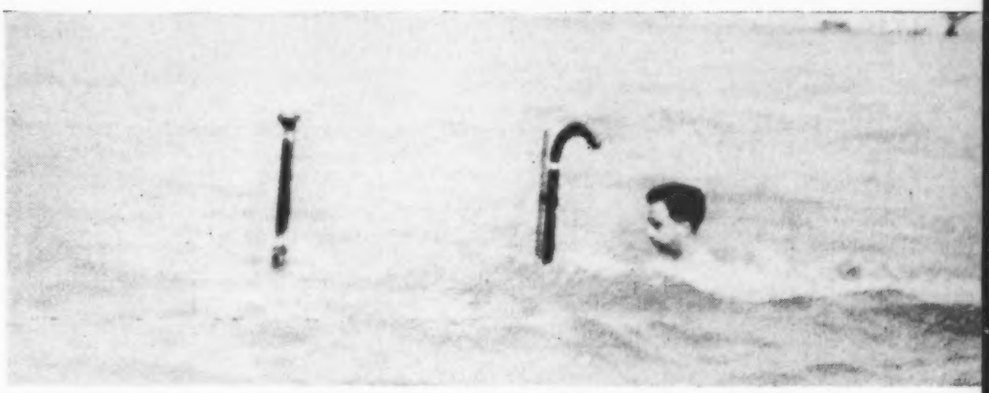
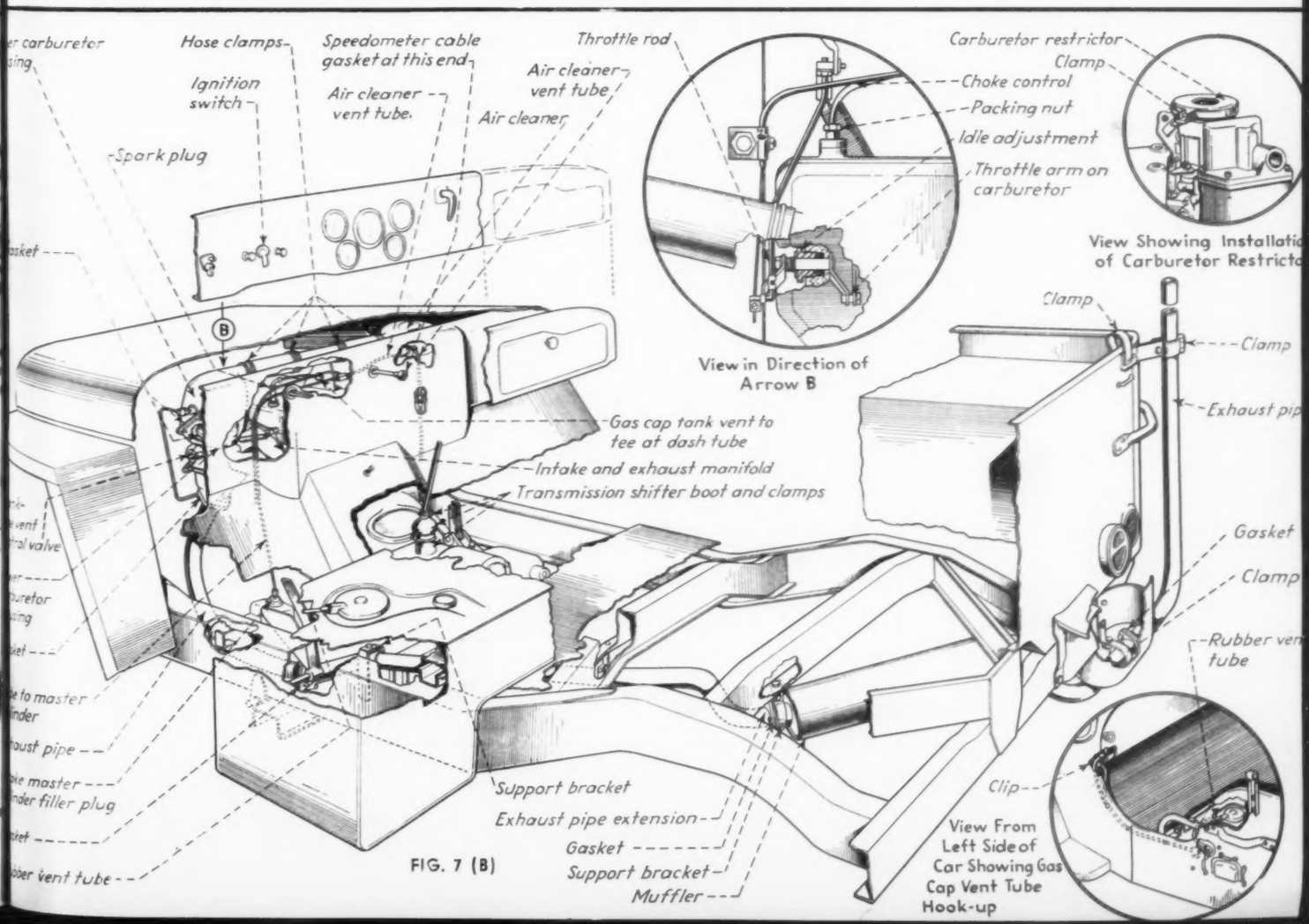


**Fig. 8—Jeep operating completely submerged in tests of the final design.**



# ENGINEERING ABSTRACTS

**FOREIGN AND DOMESTIC ARTICLES**

## Welded Tubular Lathe Beds

**Foreign Abstract condensed from "Recent Development of Fabricated Lathes and Tests With Tubular Lathe Beds", by W. Mobius, *Vereines Deutscher Ingenieure*, May 27, 1944.**

THE MAIN REASON for the slow development of welded steel machine tools lies in the lack of data available to the designer. Experience and principles acquired in connection with cast iron machine tools cannot be utilized in the design of welded structures.

The surface grinding machine is the only type of welded machine tool that has been widely used. In these machines the principle of "cellular design" has been adopted with success. In cellular design, machine structures are built by welding metal sheets into cells and then combing the cells in a unit such as a machine bed. In lathes, the cellular design has not been very successful.

To learn more about the requirements for designing welded lathes, different types of structures have been carefully tested.

As a result of some promising preliminary tests with a small lathe, four heavy lathes were built for comparative tests:

1. Standard lathe, 6½ in. center height, all cast iron except water pan.

2. Lathe with tublar steel bed with welded guide ways on cast iron feet, 6½ in. center height. Headstock, feedbox, saddle and tailstock were made of cast iron.

3. Welded lathe with tublar bed, 14½ in. center height.

4. Welded lathe with cellular bed, 14½ in. center height.

The 14½ in. center height lathes were 12ft. between centers. The largest diameter that could be turned over saddle was 18 in. and over bed was 32 in. The 25 hp. hydraulic drive of main spindle was stepless from 12 to 400 r.p.m. Standard steel plates and sheets were used for the two welded beds.

All transmission and shaft elements in the four machines were built as identical as was possible. All beds were designed to give the most favorable chip removal that could be obtained for the respective design. In the tubular bed design the chips passed over a guard attached to the rear side of the bed and accumulated outside of the machine. In the cellular bed design, the chips passed through openings arranged between the cells, and accumlated on the ribs.

The welded steel tubular bed, Fig. 1, is advantageous because of its inherently large torsional moment of resistance to the cutting forces. The reactions to the cutting forces can be better resisted with a tubular bed than with the cellular design, Fig. 2, because in the latter a complex relationship exists between tension and compression of the different members of the cells. Figs. 3 and 4 show the force systems.

Headstock, tailstock and saddle of the tubular design were also designed on the tubular principle, although it is more customary to use the cellular principle for these parts. Except for thin sheet metal pieces, ordinary gas pipes were used for supporting the gears in the headstock of the tublar bed machine, Fig. 5. Bosses were made of thick walled tubes.

The headstock of the cellular bed, Fig. 6, was built in accordance with the principles of cellular design. Flat bar stock was used for fastening the headstock to the bed and for supporting the tailstock structure. Cast iron gibs were fastened by screws to the guideways of the saddle so as to have steel gliding on cast iron.

Cost and weight of the unmachined parts of the lathes are compared in Table I. The high cost and weight of the tubular cast iron bed includes the cast iron water pan. A welded water pan is more customary.

When comparing costs, it should be noted that the parts were made at different

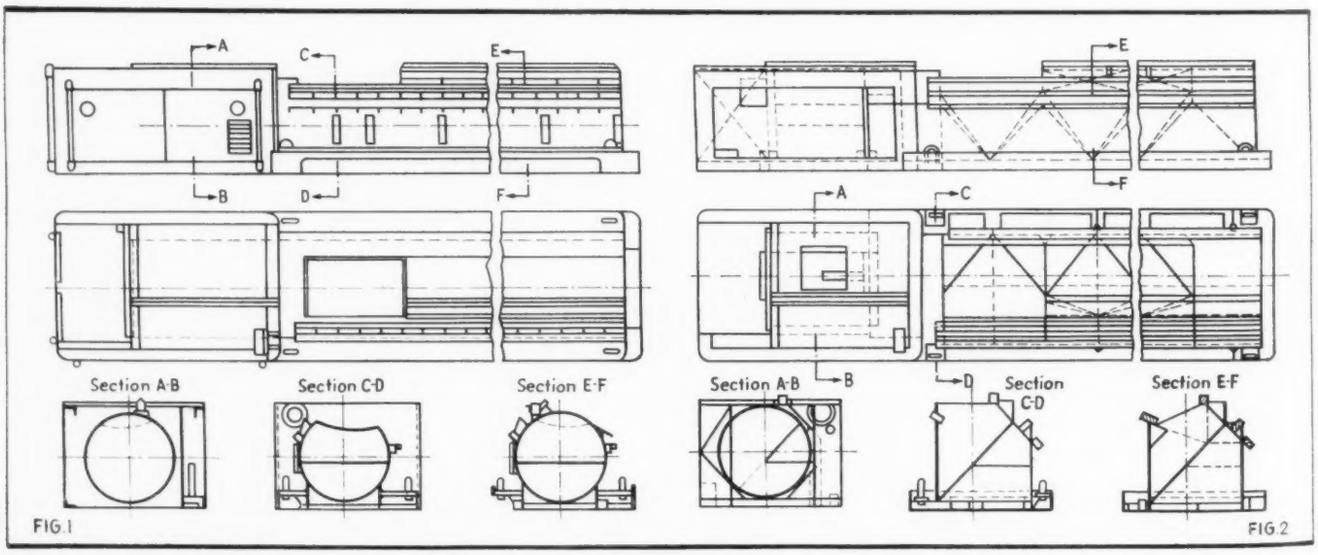



Fig. 1—Design of welded steel tubular bed. Fig. 2—Design of welded steel cellular bed.

plants and also that often higher prices were paid to get quick delivery. Cost, therefore, is not always a good basis for comparison. Appreciable saving in cost will be possible when the shops are properly equipped to manufacture welded parts.

It was also not possible to compare the cost for welding the tubular and for the cellular designs on the basis of welding hours because of different overhead in the plants. The total length of the welding seam is a fair basis. The seam is appreciably longer for the cellular than for the tubular design, hence a greater welding cost for the cellular construction had been expected.

More machining time was required for the cast iron tubular bed than for the welded beds. Tool wear in machining the cast iron beds was about 20 percent higher than for the welded beds.

About 12 percent of the reduction in weight was attributed to the hydraulic drive, in comparison with standard lathes with mechanical spindle drive.

In six different series of cutting tests, covering all possible types of turning operations, in which the deformations of the machines were measured with indicators, no appreciable differences were evident in the performance of the machines. The deflections did not exceed the normal values of standard cast iron beds. The welded headstock and tailstock showed greater elastic deformation than the cast iron design, which may have been caused by the appreciable difference in the weights of these parts.

**Table I—Comparison of Weight and Cost of Unmachined Lathe Parts**

Values in percent based on 100 for standard cast iron lathe.

| | Tubular cast iron design | | Tubular welded design | | Cellular welded design | | Mixed design | |
|---|---|---|---|---|---|---|---|---|
| | Weight | Cost | Weight | Cost | Weight | Cost | Weight | Cost |
| Bed with feet and pan..... | 112.7 | 170 | 50 | 100 | 49.5 | 114.5 | 50 | 100 |
| Headstock and gear guard.. | 100.5 | 102 | 49 | 267 | 45.5 | 107.9 | 100 | 102 |
| Compound rest..... | 52 | 55 | 59 | 55 | 59 | 55 | 52 | 55 |
| Saddle and Apron..... | 88 | 82 | 55 | 180 | 46 | 100 | 88.5 | 82 |
| Tailstock..... | 115 | 106 | 69 | 255 | 54 | 133 | 115 | 106 |
| Steady rest..... | 103.5 | 96 | 71 | 280 | 62.5 | 143.5 | 100 | 95.6 |
| Total..... | 105 | 145 | 51.5 | 145 | 48 | 112 | 65 | 97.5 |

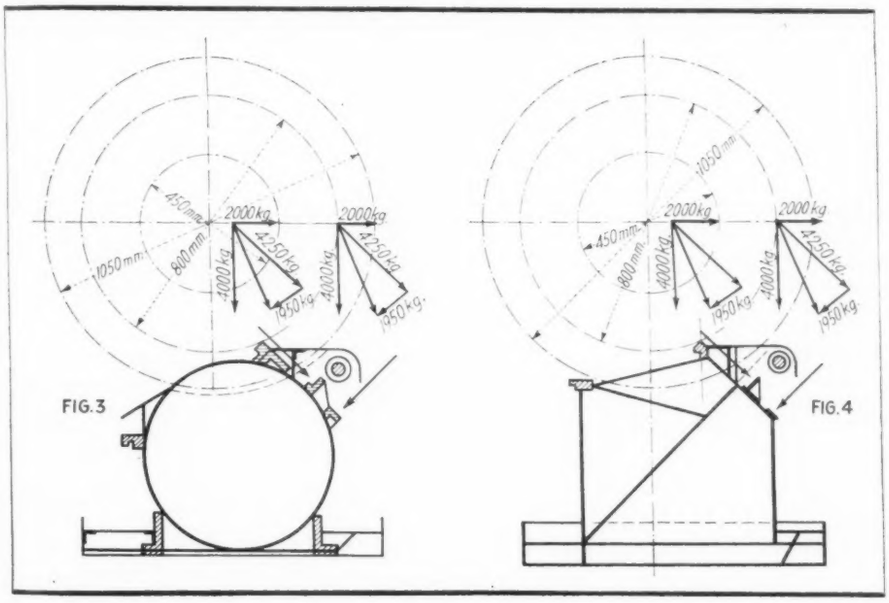



Fig. 3—Force diagram for tubular bed. Fig. 4—Diagram for cellular bed.

The surface produced on the workpieces was faultless. There were no chatter marks and no disturbing effects of vibration could be found during the shop tests. Even after six months of continuous use of the machines no complaints were received. It is believed that the hydraulic spindle drive contributed appreciably to this success because the cutting speed could always be adapted to the particular conditions of the set-up.

In addition to the shop tests, investigations were made to obtain design data. The machines were loaded statically by applying loads of about 1,100 lb. at different places. It was found that the deflection at the rear guide way of the welded tubular bed was appreciably smaller than at the cellular bed, but greater than for the cast iron bed. The comparative figures were 100 for the cast iron tubular, 280 for the welded tubular and 1,140 for the welded cellular design. Similar results were obtained at other spots.

Too much emphasis should not be placed on tests with static loads applied at certain points of the machines, for under actual cut-

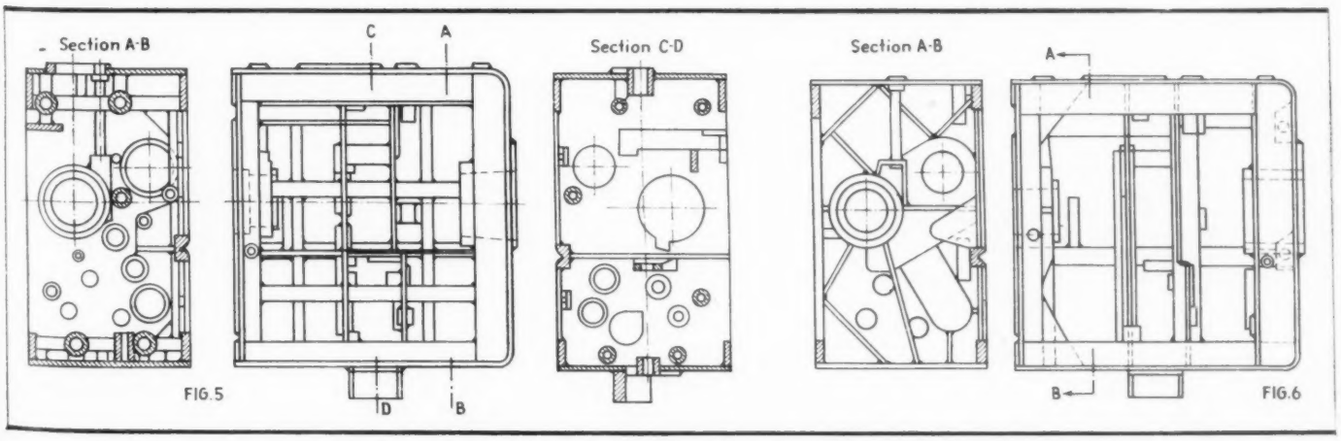



Fig. 5—Headstock built on principles of tubular design. Fig. 6—Built on principles of cellular design.

ting conditions the load is not concentrated, it is distributed over the bed because of the length of the guide ways of the saddle.

Vibration tests were also made, using a vibrometer and Heyman's vibration tester. The amplitudes measured crosswise to the bed and to the saddle were greater than the vertical amplitudes whenever the machines were running at or near the critical speed of the hydraulic drive. At maximum speed, the amplitudes were greatest crosswise to the headstock.

To determine the effect of the measured vibrations on the performance of the machines, finishing cuts were taken. The finish of the work, was always satisfactory for all positions of saddle and for all speeds.

It was concluded that the frequencies are high and the amplitudes small. Resonance was not noticeable and no chatter marks visible on the work even where the higher modes of vibration of certain machine parts were close to the natural frequency.

In the results of vibration measurements on the idling machines the curves for the cast iron design were always uniform, but vibrations were noticeable in the welded design particularly in the horizontal plane crosswise to the bed. Vibrations for the tubular steel bed and the cast iron bed were the same. The cellular bed is favorable regarding vibrations measured in a horizontal plane crosswise to the bed.

CONCLUSIONS. In comparison to the cellular bed the tubular bed is more favorable both statically and dynamically measured crosswise to the bed. It is also more favorable in longitudinal vibration; but evaluation of further tests is necessary before definite conclusions can be drawn. The tubular bed is also more advantageous with respect to chip removal. The welding seams of the tubular design are shorter than for the cellular design.

The rigidity of the cellular design can still be improved.

A mixed construction, that is, a combination of a steel bed with cast iron headstock, tailstock and saddle will give a satisfactory machine in every respect. The large parts are more advantageous in steel, the small ones in cast iron. This statement should not be understood as excluding the possibility of future development towards complete steel design.

## Rapid Reversing Drives

**From a paper, "Problems in Applying Rapid Reversing Drives", by R. H. Clark, Warner and Swasey Company, presented at the Westinghouse Machine Tool Electrification Forum, April 9, 1946, Pittsburgh, Pa.**

RAPID REVERSING TYPE MOTORS are usually applied on machines to obtain:

1. High starting torque for fast acceleration.
2. High reversing torque for fast and accurate plug stops and reversals.
3. Operation under severe duty cycles without overheating and low maintenance.

Reasons why rapid reversing motors are not more widely used, include:

1. Motors are special and expensive.
2. In many cases, machine production is limited by reversal capacity of the motor.
3. Difficulty in obtaining exact motor application data.
4. The great amount of development work required of the machine builder, as well as the electrical manufacturer, before a successful machine is produced.

One of the latest designs by Warner & Swasey engineers to use rapid reversing motors is a 16-inch semi-automatic special purpose turret lathe. Obtaining the two-speed motor with satisfactory reversing capacity was the greatest single problem in the design of the machine. Because most of the brass and other light metal work produced on this machine is held in large chucks and fixtures, the $WR^2$ external to the motor is large, sometimes being ten times that of the $WR^2$ of the driving motor. This condition requires careful design of motor ventilation and insulation for satisfactory reversing capacity.

Electrical designers can do much to make the application of such motors easier by clearing away some of the air of mystery that surrounds the engineering theory involved. Published application data consisting of rotor $WR^2$, reversal capacity, starting currents and torques, plugging currents and torques on motors suitable for reversal or plug stopping service would be helpful. For multi-speed motors, the motor heating interrelation between starts, plug stops, speed changes and reversals for the various speeds, would help establish maximum machine performance.

Similarly, the machine tool engineers must furnish to the motor manufacturer accurate data on machine $WR^2$ duty cycle (or equivalent motor reversal capacity) on which to base the motor design.

## Ten Hints for Designers

**From a paper, "A User's Future Requirements For Machine Tools," J. R. Weaver, Manager, East Springfield Appliance plant, Westinghouse Electric Corp., presented at the Westinghouse Machine Tool Electrification Forum, April 10, 1946, Pittsburgh, Pa.**

BECAUSE of many new economic pressures the following ten factors are probably typical of future requirements of machine tools:

1. Size. Space is an important factor in production. Despite more and larger factories, it is economical to hold space to a minimum, so tools should be compact.

2. Ease of operation. Machines should require operators with minimum skill. This is true from a simple drill press to a complicated automatic machine. Need for simpler operations is because of labor's drive to increase the wages of the lower priced operator in greater proportion to the skilled mechanic. Therefore, the inclination to learn a trade is becoming less and less. The machine tool must supply the skill formerly possessed by the operator.

3. Maintenance. For the same reason, maintenance of the machine must be kept to a minimum. Repairs should be made in the simplest way. Possibly instead of repairing machines, it will be necessary to design them so that worn parts can be easily replaced by new factory parts.

4. Electrical advances. Electrical developments should be made in motors or control applications to reduce hand operations to a minimum.

5. Increased accuracy. Of increasing importance to designers is that better, faster, and more accurate means of inspection and measuring work are being developed and perfected. The record of accuracy accomplishments in the machine tool field is remarkable, but the effort for still more accuracy should be continued.

As a manufacturer using a large number of machine tools, experience shows that the best quality and lowest cost production is obtained by making all the parts to very close, and ever closer tolerances. Reducing tolerances inevitably results in faster and surer assembly and a better product, and usually results in better overall economy. Take as an example the manufacture of refrigeration compressors. A piston and cylinder mechanism is utilized to pump the refrigerant. The piston has no rings. To obtain a mechanism that is quiet, efficient, and trouble-free, the difference in the diameter of the piston and the cylinder must be held to a nominal 0.0005 inch. To achieve this fit, selective assembly is used. Pistons and cylinders are accurately measured, marked with an electric pencil, and matched into 16 groups.

More accurate manufacturing of these parts would cut costs tremendously, save rejects, and produce a more efficient machine. If parts could be easily measured to a millionth of an inch, machine tool builders would be expected to produce machines accurate to a millionth of an inch.

6. Construction. It is probable that closer tolerances will require increased attention to stiffer, more rigid construction. More sturdy construction also may be necessary to withstand greater forces for faster removal of material.

7. Thermal expansion. Another point that it may be necessary to consider is the use of construction materials equivalent to "Invar" with near zero temperature coefficients of expansion to eliminate inaccuracies in operation because of overheating.

This would increase available productive hours of a tool by eliminating warming up time and the necessity for resetting tools near the start of the run. It would also reduce scrap losses and permit more efficient operation with less skilled workmen.

For example, one production problem involves thermal expansion in producing refrigerator compressor crank shafts. Because of temperature changes in the machine used to grind the bearing surface on this shaft, the machine dimensions change and production is reduced. Various methods of solving this problem are now being studied —including the use of "Invar" and the refrigeration of some of the machine parts.

8. Reducing set-up time. Another desirable objective in machine tool design is to develop features to pre-set cutting tools to give finished tolerances on a piece without so much cut-and-try. Also, methods of expeditious gaging and measuring the machine surfaces produced should be developed so that when the operation is completed it will be correct.

9. More special-purpose tools. There should be further development of special-purpose tools in place of multi-purpose tools, by elimination of adjustments and adaptations not necessary for the specific job. In the past, machine tools have been capable of accommodating a wide range of sizes of work and have had built into them facilities and features for doing a thousand and one operations. Rarely does a manufacturer of mass production items make use of more than a few of these facilities. Better bearings, protection of bearings, automatic lubrication, and scientific use of coolants may be especially helpful on these special-purpose tools.

10. Dream tool of tomorrow. Engineers are already working on new designs that will eventually make today's appliances obsolete. What kind of a machine tool will we need to build these new products?

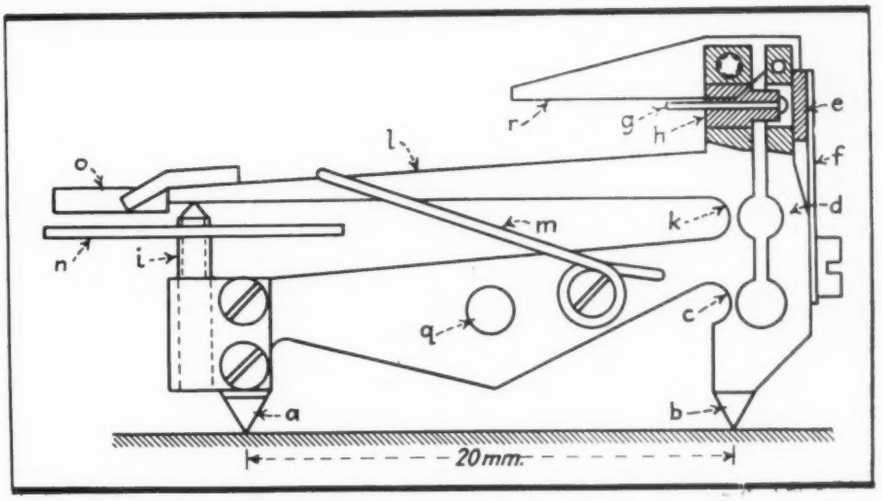
Probably the aim will be to eventually perform all the operations on a piece with one machine. A machine to do this will combine many dissimilar operations and probably be relatively smaller in size and yet be sufficiently flexible to take care of periodic changes in design of product. When necessary to change the hold of a piece to complete the operation, positive and automatic transfer means must be devised. For example, one piece of a Bug Bomb Aerosal Dispenser requires five separate machines: Punching, drawing, trimming, embossing, and piercing, and the parts must be conveyed between machines for each of these operations.

If one machine could do all these operations floor space, transportation, operators, and man hours, would be saved. Steel sheet could come in on a spool at one end—finished pieces would come out into a hopper at the other end.

## "Signaling" Stress Meter

**Foreign Abstract condensed from an article by A. Thum and O. Svenson in *VD1-Zeitschrift* (Germany), March 18, 1944, page 153.**

A SIMPLE INSTRUMENT was developed by the German Bureau of Standards, Barnstadt Branch, for measuring the maximum and minimum values of periodically changing stresses in machine parts. In the instrument, shown in the accompanying drawing the stress-elongation of the material taking place between the fixed and the movable edge (*a* and *b*) is transmitted to lever (*d*) which is pivoted about a point (*c*). Attached to the lever is a leaf spring (*f*) carrying an electric contact plate (*e*) at its upper end. A pin (*g*), located opposite the plate, is electrically insulated from the body of the instrument and can be adjusted by means of lever (*l*) which is deflected about point (*k*) by motion of a precision screw (*i*). Spring (*m*) keeps lever and screw in contact.




**Stress Meter: *a*, fixed edge; *b*, movable; *c*, pivot for *b*; *d*, lever arm; *e*, electric contact plate; *f*, leaf spring; *g*, contact pin; *h*, insulating material; *i*, adjustment screw; *k* pivot of lever *1*; *1*, lever arm; *m*, spring; *n*, disk with scale; *o*, pointer; *p*, locking lever; *q*, hole for clamping.**

The horizontal adjustment of the pin can be read from the disk scale (*n*) which is attached to the screw, because the adjustment depends on the position of this screw relative to pointer (*o*). Pin and plate are connected to an electric circuit (not shown in drawing) in which an electric light bulb or any other type of current indicator is installed.

When the machine part is subjected to periodical stress variations, the standard distance between edges *a* and *b* (20 mm. or about 0.8 in.) will vary and the upper end of the lever will consequently fluctuate between two limits. At the instant of minimum elongation, the lever is in its most outward position, and at the instant of maximum elongation it will be in the most inward position.

By turning the disk it is possible to adjust the pin so that it just misses contacting the plate at the instant of greatest elongation. The light bulb in the circuit will therefore stay dark. On the other hand, when the pin is so adjusted that it just contacts the plate at the instant of smallest elongation (i.e. when the lever is in the outward position) the light bulb will burn continuously.

The "threshold" of contact and of separation of the pin and disk therefore indicates the maximum and minimum stress value. These limits be read from the scale and also "signaled" by the light bulb. The hole (*q*) serves for clamping the instrument. When the stress change is rapid it is advisable to solder or to screw the instrument to the work.

ACCURACY. The accuracy of the instrument is dependent on the precision of the screw and on the finish of the pin and plate. A measuring accuracy of plus or minus 0.0004 mm. (about 0.000016 in.) can easily be obtained. With a standard measuring length of 20 mm. (about 0.8 in.) a change in length of 0.0004 mm. corresponds to a single axis stress of 0.4 kg. per sq. mm. (about 560 lb. per sq. in. for steel and to 0.1 to 0.2 kg. per sq. mm. (about 140 to 280 lb. per sq. in.) for light metals.

APPLICATION. It is often advisable to preadjust the instrument to an approximate value by observing the light bulb. Instead of installing a light bulb, other means for indicating or signaling the stress limits can also be used—ear phones, galcanometers, and photographic recorders. The instrument can also be connected to a warning device which would sound off in case of permanent overloading of a machine part.

## Method of Calculating Beam Coefficients

**From "A Simple Tabular Method of Calculating Deflections and Influence Coefficients of Beams," by N. O. Myklestad, published in *Journal of the Aeronautical Sciences*, January, 1946, page 23.**

A METHOD of finding deflection curves and influence coefficients that can be readily applied to cantilever beams and to simple beams with or without overhangs. The method is fast and accurate when a calculating machine is available, but slide rule accuracy is probably sufficient for most practical purposes. An additional advantage is that the calculations can be performed in a routine manner by a computer who knows nothing about beam theory.

The beam is assumed to be weightless and to carry a finite number of concentrated forces. The method consists of using elastic coefficients to find the difference in the slopes at the two ends of the beam and also the difference in the deflections when the slope at one end is zero. The entire beam is then rotated about the end that has zero slope, until the boundary conditions at the other support are satisfied.

# AUTOMATIC CONTROLLING MECHANISMS

Automatic valve operators, designed to control valves remotely and automatically, generally depend upon electricity or fluid pressure for their actuation. The valves themselves may be of either the single or double-seat type depending upon conditions of line-pressure fluctuation, pressure drop and duration of shut-off periods. Some of the operators utilizing pressure and electricity for actuation are described and illustrated below.

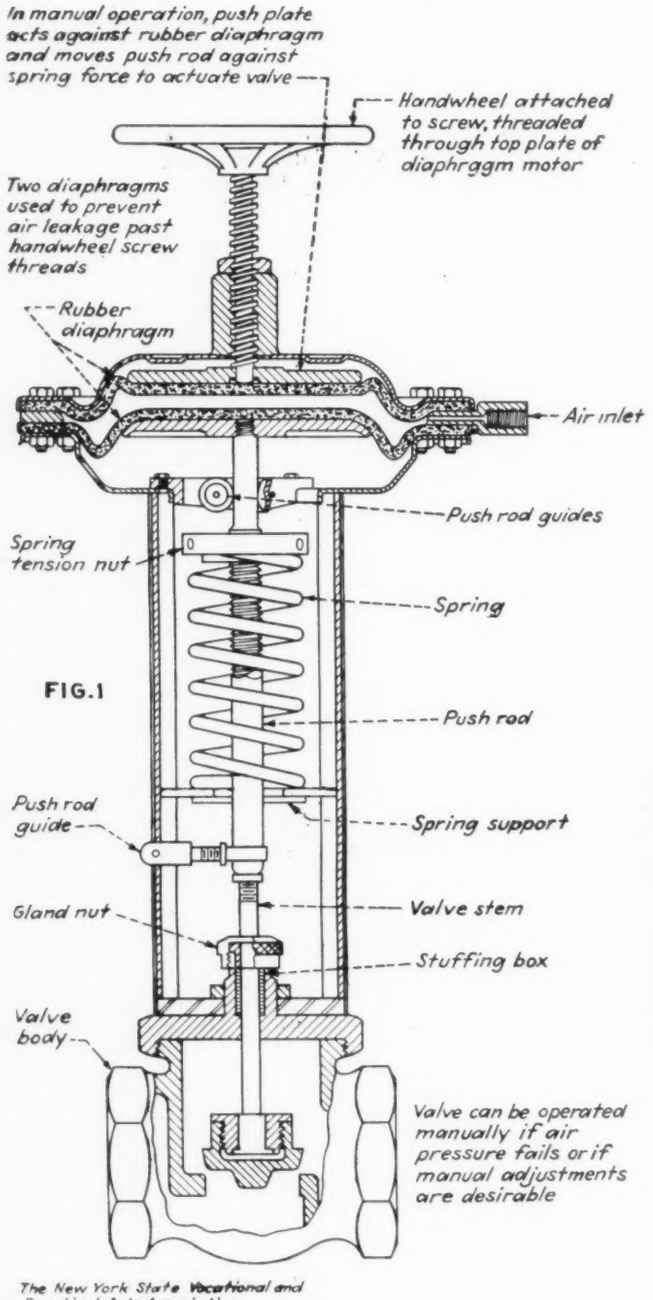

In manual operation, push plate acts against rubber diaphragm and moves push rod against spring force to actuate valve
Handwheel attached to screw, threaded through top plate of diaphragm motor
Two diaphragms used to prevent air leakage past handwheel screw threads
Rubber diaphragm
Air inlet
Push rod guides
Spring tension nut
Spring
Push rod
Push rod guide
Spring support
Gland nut
Valve stem
Stuffing box
Valve body
Valve can be operated manually if air pressure fails or if manual adjustments are desirable

FIG.1

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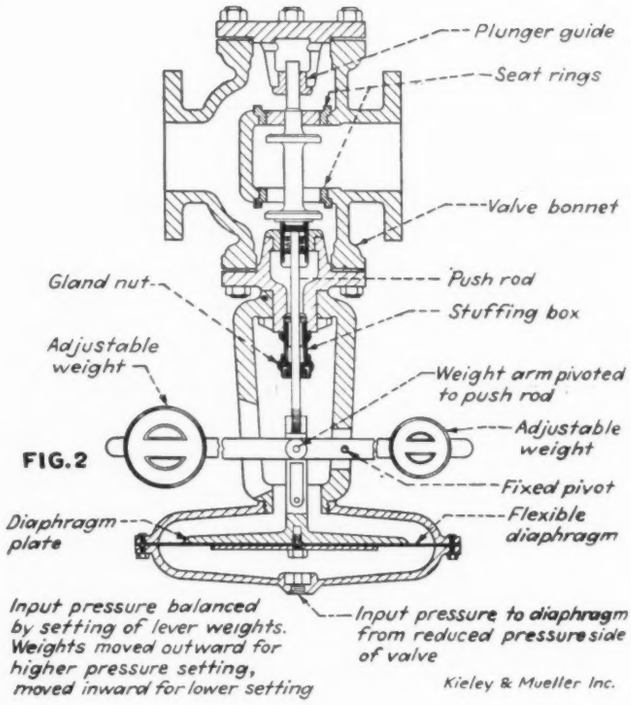
Plunger guide
Seat rings
Valve bonnet
Push rod
Gland nut
Stuffing box
Adjustable weight
Weight arm pivoted to push rod
Adjustable weight
Fixed pivot
Flexible diaphragm
Diaphragm plate
Input pressure balanced by setting of lever weights. Weights moved outward for higher pressure setting, moved inward for lower setting
Input pressure to diaphragm from reduced pressure side of valve

FIG.2

Kieley & Mueller Inc.

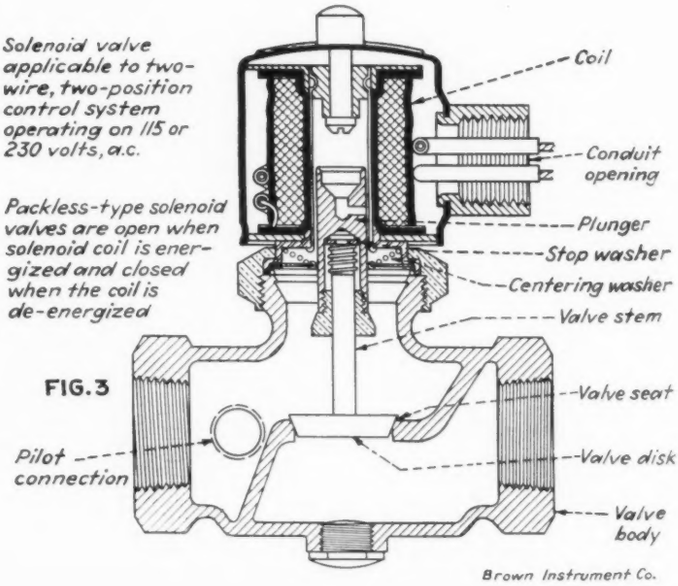
Solenoid valve applicable to two-wire, two-position control system operating on 115 or 230 volts, a.c.
Coil
Conduit opening
Packless-type solenoid valves are open when solenoid coil is energized and closed when the coil is de-energized
Plunger
Stop washer
Centering washer
Valve stem
Valve seat
Pilot connection
Valve disk
Valve body

FIG.3

Brown Instrument Co.

# FOR VALVE OPERATION—I

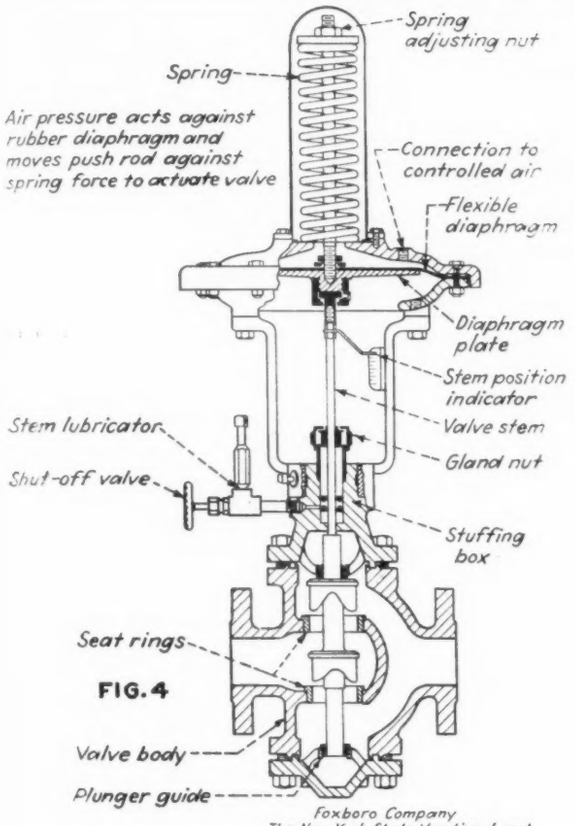


FIG. 4

Foxboro Company
The New York State Vocational and Practical Arts Association

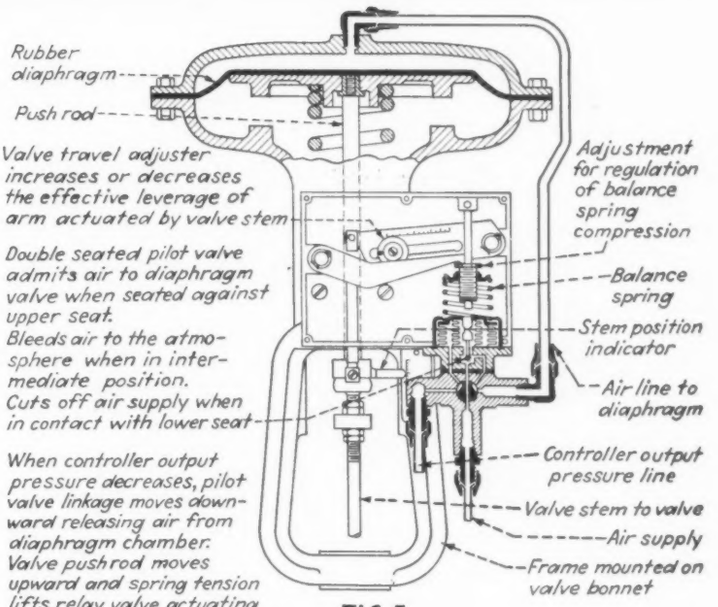
Rubber diaphragm
Push rod
Valve travel adjuster increases or decreases the effective leverage of arm actuated by valve stem
Double seated pilot valve admits air to diaphragm valve when seated against upper seat. Bleeds air to the atmosphere when in intermediate position. Cuts off air supply when in contact with lower seat
When controller output pressure decreases, pilot valve linkage moves downward releasing air from diaphragm chamber. Valve push rod moves upward and spring tension lifts relay valve actuating linkage, restoring equilibrium
Adjustment for regulation of balance spring compression
Balance spring
Stem position indicator
Air line to diaphragm
Controller output pressure line
Valve stem to valve
Air supply
Frame mounted on valve bonnet

FIG. 5

When controller output pressure increases, relay valve actuating linkage moves upward admitting air to diaphragm chamber and moving valve and linkage downward until equilibrium is restored

Moore Products Co.
The New York State Vocational and Practical Arts Association

Valve positioner used in conjunction with diaphragm valve to compare actual position of valve with that called for by the instrument output pressure. Valve positioning relay used to overcome residual friction between valve plunger and ports

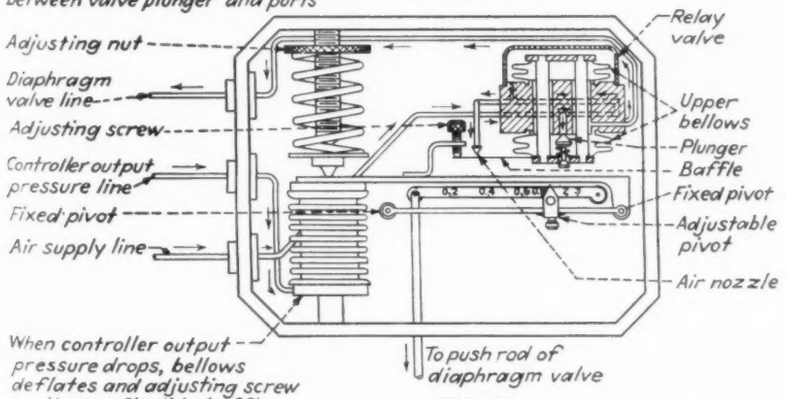


FIG. 6

When controller output pressure drops, bellows deflates and adjusting screw resting on flexible baffle moves baffle away from nozzle. When controller output pressure rises, baffle moves closer to nozzle increasing back pressure above upper bellows and forcing bellows unit downward, and moving plunger away from air supply opening

The New York State Vocational and Practical Arts Association

Valve positioners required for fluids of high viscosity, corrosive chemicals, or excessive distances between valve and controller, since quick response is aided by positioner as low pressure air to diaphragm motor does not have long and high resistance path to travel

When plunger is moved away from air supply opening, air supply pressure passes directly to diaphragm valve line tube

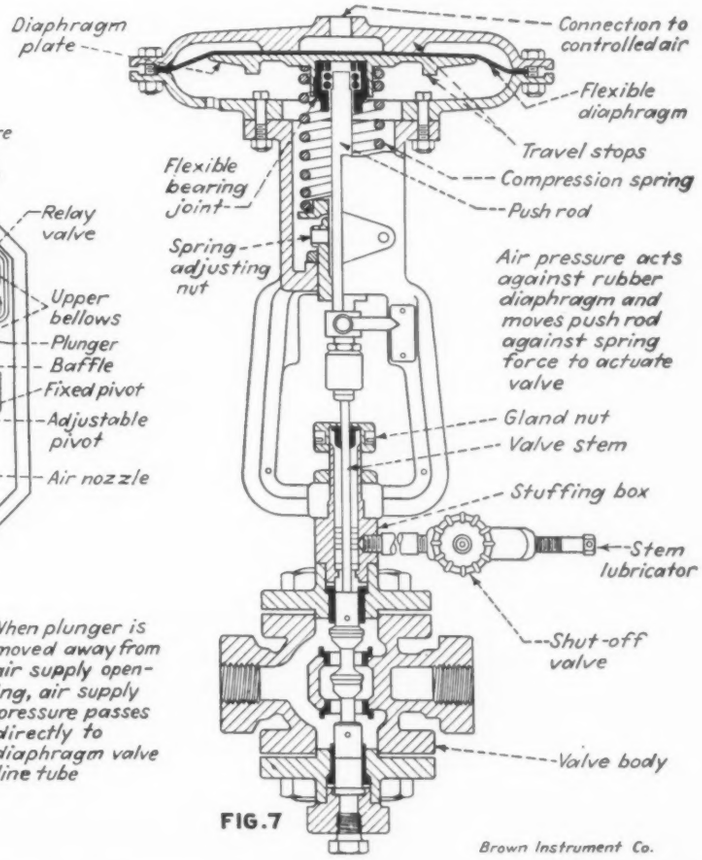


FIG. 7

Brown Instrument Co.

# Translating Inventions Into Marketable Products

**S. BERTRAND BARNARD**
Consulting Engineer

**Factors such as financing, development and research, production and marketing are discussed in detail. The author warns of the pitfalls awaiting the inventor who does not evaluate his own invention realistically.**

NO FIELD OF ENDEAVOR is so difficult to prescribe as the field of invention. Even the most learned judges cannot agree on a uniform definition of the word "invention", from a patent standpoint. The fact that the inventor is probably one of the most highly individualistic members of our society complicates the problem still further.

Insofar as the commercial development and the reduction to marketable products of new inventions, inventors can profit by the experience of others in the field.

## Problem

Before he spends his time and money, and that of relatives and backers, the inventor should study carefully the problem he is trying to solve. Assuming that all obstacles of engineering, finance, production, patents and marketing are solved, is his brain child really an improvement over other devices on the market, or is it merely a longer, costlier, slower method of accomplishing something that has been done for years?

In order to produce a new product or method it is advisable to study carefully what has gone before, to avoid duplicating mistakes of the past. It is even possible to learn, by a process of elimination, the things not to do, and in this manner come up with a reasonably practical solution.

It is well to remember that all engineers and manufacturers in the country are not wrong, and that very often public tastes, habits, questions of costs, and similar factors, affect the marketability of a product. Improvements, devices or methods which tend to cut costs and increase the market for a product, are far more readily acceptable to manufacturers than those which increase costs.

## Fundamental Principles

While the fundamental laws of mathematics, physics, chemistry, are continuously being expanded in scope, and while extended research and refined methods enable us to measure physical factors more accurately than was ever possible before, the fundamental laws of nature remain substantially unchanged. There are always revisions of fundamental physical concepts being made, but the odds are very much against the semi-professional inventor revising them. While an inventor may be another Steinmetz or Einstein, it is safer to assume that he is not until he can prove otherwise.

## Patent Procedure

An inventor should be extremely careful in the selection of a patent attorney and patent advisors. The best invention can be materially weakened by flaws in patent applications or errors in the prosecution of patents.

The writer hesitates to engage in public controversy by citing figures on issued patents which have inherent weaknesses, serious or minor, which affect the validity and strength of the patents. The figures are, however, far greater than is generally known.

The inventor should select an attorney with the proper background and experience to handle his application and not try to obtain a quick, cheap patent. Sometimes it is even advisable to have the attorney's work rechecked by another attorney with, of course, the consent of the original attorney, to avoid any possibility of error. Litigation on a patent often hinges on the meaning of a phrase or a word; the importance of claim drafting is therefore apparent.

It is also necessary for the inventor to study the scope of his patents with extreme care. Too often an inventor will, in the course of the development of a product, unwittingly go entirely beyond the scope of his patent coverage, without realizing it.

It is important, therefore to check issued patents and patent applications at various stages of the development, and to file new patent applications to cover new features not covered by the earlier applications. This is especially true today, as the modern patent becomes increasingly specialized, caused by the thousands of devices that have been developed in the past, and the additional thousands of unpatented products produced, or described in publications. Although this procedure is necessarily costly, it is the only way in which adequate patent protection can be obtained on products which are the result of sustained development over a long period of time.

The writer has analyzed a large number of patents and has often found that only a few minor features are covered and in many patents the final product is entirely out of the scope of the patent and, therefore, totally unprotected. This is often startling to the inventor or manufacturer, who believes that he has obtained adequate and complete patent coverage, broad enough to include what he assumes to be minor improvements.

## Engineering

Inventors can spare themselves trouble, and the expenditure of thousands of dollars if they obtain the advice of a competent engineer, familiar with the field in which they are operating. While the engineer is not infallible, and while there is often a diversity of opinion among engineers, it is reasonable to assume that an engineer who is thoroughly trained and has devoted a substantial portion of his life to a particular field, knows something about it. If the inventor does not want to accept the opinion of one individual he can match it against the opinion of another.

The inventor should not, however, proceed on the assumption that everyone in a given industry is entirely wrong, and that he alone will revolutionize that industry. It has been done in the past, but the chances of the semi-professional inventor producing this type of discovery are slim indeed, particularly in view of the complication of modern industry.

## Testing

Before a product is released for marketing, it should be thoroughly tested, under varying climatic and operating conditions, to ascertain whether it will stand up in service.

Too often success of product that has

good commercial possibilities is prevented by premature marketing. To receive public acceptance over a sustained period, a product must be as nearly foolproof as possible. The first year after introduction of a new product is the most critical. A small mistake in design, production or marketing may prove costly or even disastrous.

Often hundreds of thousands can be saved in the introduction of a new product, by testing the reaction of the consumer, or field testing in a small area, before general distribution is attempted.

### Personal Habits and Mental Inertia

While in certain fields of endeavor such as aeronautics and electronics, acceptance of new devices and improvements is generally faster than in more conservative fields, the world will not accept violent revisions in its mode of living overnight.

War and the upheavals and the urgent problems precipitated by war, of course, alter this phase of the problem tremendously. Money for development is also poured out in time of war at a rate which would be utterly impossible in peacetime. Except in the case of novelties, which are accepted more or less instantaneously and drop off with equal rapidity, most products introduced on the market, find a long, hard road to travel.

Modern methods of advertising and distribution often reduce the time for public acceptance of new products substantially, but unless an invention results in a substantial improvement, or lower cost on a product that has already received wide public acceptance, the chances are that broad markets are a matter of years and not months.

### Financing of Inventions

The financing of new and untried inventions in the embryonic stages is something for which no accepted formula or procedure is available. Unless an inventor is financially capable of carrying the initial burden himself, or has a group of friends who will back him on faith, the problem offers considerable difficulty.

Patents, development and research work, tooling, production and marketing are costly. Not often are adequate funds available to the point where an invention can be either marketed independently or sold to a manufacturer.

There are, however, a number of patent agents, individuals, financial groups and manufacturers on the alert for new products, who will finance an idea through its growing pains to the point of ultimate acceptance; but these are none too plentiful.

On certain types of inventions there are a number of public, and semi-public institutions which finance work of this type. These institutions, however, confine their activities to limited types of inventions, which offer major advantages to the public in general or to problems of national defense.

On most inventions the independent inventor must go through a process of trial and error in obtaining adequate financing, unless he is well supplied with his own funds.

Except in the case of small products, which require inexpensive manufacturing facilities and tools, the problem of producing new products offers further difficulties. As a general rule it is more advisable to license or sell an invention to an established manufacturer than to attempt production and distribution under present conditions.

Modern high-quality, low-cost production is a highly specialized field in itself, and therefore beyond the scope of the average independent inventor.

The established manufacturer has the necessary facilities and organization and is often anxious to obtain manufacturing rights to marketable products. He can spread the risk between established products and new developments and therefore does not take as great a gamble as the small independent manufacturer of a new product.

Under present legal restrictions, public financing of new and untried companies, for peacetime activity is almost impossible except in unusual cases where the background of the inventor and the merits of his product warrant it. While the independent inventor is often the world's greatest individualist, he will generally find that sharing the risk and the profits with an established manufacturer, or financial group is generally far more profitable and secure in the long run.

### Distribution and Marketing

Modern distribution, advertising, sales promotion and marketing have become highly specialized, costly problems. It is far better to entrust a product suitable for national distribution to an established marketing organization, than for the inventor to attempt it.

While some products have dramatic appeal and obtain sizable markets without great sales effort or expense, these are generally quite rare. Most products must be sold and distributed intensively, in order to be profitable and withstand competition.

The average inventor is temperamentally unsuited to problems of finance, sales and advertising which go to make a modern business successful on a broad scale. He would do well to place these problems in the hands of others better suited by temperament and experience to handle them. He can then keep his mind free for further development and improvement of the product or method. The latter is vital in this day of violent change and rapid obsolescence.

### Sale of Inventions or Patents

The sale of inventions or patents is as difficult, if not more so, than the sale of any other intangible item involving substantial sums of money. The payments made by the financier or manufacturer for inventions are really only a small part of his investment, as his costs of development, production and marketing begin after he acquires the manufacturing rights.

Most inventors, or their representatives, in attempting to sell inventions often tend to be fragmentary and incomplete. It is well to remember that the financier or manufacturer is primarily interested in the probable financial return from the marketing of an invention and not in its romance.

To simplify the problem of such a sale or licensing arrangement, the inventor should be prepared to present as complete a story as possible. While he may not feel it advisable to present this information in detail until preliminary contracts are signed, he should be prepared to offer the data as completely as possible in order to make an advantageous contract. It should include the following:

1. A detailed description of the invention, together with an analysis of the improvements it offers over similar devices now on the market. This should be as clear and concise as possible, and should be explained in such a manner that it is readily understandable by a non-technical business man.

2. A list of all patents issued covering the invention, together with a list of all patent applications filed or in preparation, which cover the invention or any contemplated improvements thereon.

A summary of all patents and applications should also be presented, giving an indication of the scope of the patents and their probable applications. This is probably the most critical phase of the sales problem; regardless of the value of the invention, the patent coverage is the only thing which offers the purchaser any protection or prospect of profits. It is also well in this regard to present an analysis of differences between the patents offered and previous patents issued on similar devices.

3. A careful summary of the inventor's training and experience in the field of the invention, particularly if he is to follow through with the development and manufacture of the invention. The inventor's background usually carries considerable weight with manufacturers, or their representatives. This is particularly true of financial men.

4. An analysis and careful estimate of the potential market for the product. This should give an indication of the size and type of market, the type of distribution required and, if possible, an indication of estimated detailed sales figures over a period of years. It is well to remember that the buyer is a business man, and that too optimistic a picture is often harmful.

5. Wherever possible a list of actual or potential competitors should be presented. It is advisable to include the reasons for the superiority of the new product over those offered by competitors.

6. The price at which the product is to

be sold, should be given, bearing in mind the cost of production, direct and indirect, manufacturing overhead and administration, the sales and distribution costs, the royalties to be paid to the inventor and the manufacturer's estimated profit.

Prices and sales should be graduated, on the assumption that increased production will generally substantially lower costs.

7. An estimate on the part of the inventor of the additional development required, including a time estimate, a cost estimate, and the number and type of engineers and technicians required.

8. An estimate of the capital outlay required, including development cost, royalty payments, equipment, tooling, inventory cost and initial marketing cost.

9. Potential profits to the manufacturer based on the above figures. This should be based on a reasonably complete cost, an estimate of potential sales on a variable scale, and a selling price equal to or lower than competitive articles.

The writer is fully aware that few inventors or their agents would be willing to present the above data with any degree of accuracy. It is nevertheless included as an indication of what the purchaser, manufacturer or financier looks for in an invention. based on the writer's experience in transactions of this type.

Even if the inventor does not wish to present detailed figures and data of this type, he will do well to prepare it for his own use. He will find that hidden factors and intangibles which he often excludes, generally increase the cost beyond his own preliminary estimates, and that competition will not allow as large a spread between his selling price and that of competitors as he would like. It is well to include in the sales price a substantial allowance for distribution, advertising and sales expense.

In calculating his royalty, an inventor should analyze the market and ascertain how large a royalty a product can stand. Inventors often delude themselves on this subject, and by demanding excessive cash payments and excessive royalties, find otherwise salable inventions on their hands for years, without any substantial realization.

### Self Appraisal

The usual attitude of the inventor toward his invention is thoroughly understandable. It is his brainchild, it represents months or even years of continuous effort on his part in working it out, as well as a sizable investment on either his part, or that of his backers.

From this point he often proceeds on the assumption that his invention is perfect, that the market for it is absolutely unlimited, and that it is so far superior to competitive products, that they are not even worthy of comparison.

The writer has seen this ostrich-like attitude cost inventors hundreds of thousands of dollars, only to produce products of doubtful commercial value. There have even been thoroughly practical men with years of experience in the development field, who have closed their eyes to fundamental physical laws, when appraising their own inventions.

This is not written in an effort to discourage the independent inventor. Many of them will, by their energy and ingenuity disprove some of the statements made here.

An inventor is a skilled craftsman with a brain. He should study his trade or profession carefully and diligently. He should seek and accept willingly the advice and assistance of highly trained and specialized engineers, patent attorneys and businessmen, in order to obtain the best results from his efforts.

He must either be prepared to expend substantial sums of his own or obtain adequate financial backing in order to translate his ideas into a marketable product or process.

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# Gear for Gas Turbine Plane

A COMPACT, lightweight gear which is destined to hasten the output of a new type of commercial airplane powered by a geared gas turbine has been designed and built at the Nuttall Gearing Division of the Westinghouse Electric Corporation. Having a reduction ratio of 10 to 1, it will reduce the 12,000 rpm. speed of a large gas turbine to 1200 rpm. at the propeller.

Geared gas turbine airplanes which harness the power of a turbine engine to turn a propeller instead of exhausting a high velocity jet into the atmosphere are expected to have distinct advantages in economy and load-carrying ability.

Propeller tip speed limitations are reached somewhat below the speed of sound, approximately 750 miles per hour, because propeller blades would be torn from the shaft at higher speeds. Thus it becomes necessary to have a reduction gear which will add little to the overall weight of the plane.

Development of this reduction gear marks the first time that such a compact unit has been made for the handling of so great a load. The new gear, shown below including the propeller shaft support, weighs only about 1/30th as much per hp. as an industrial gear.

This new drive consists of one set of high speed planetary gearing that transmits its energy to a low-speed planetary gear set, all in the same housing.

Special carburized and nitrided steels are used in making the gears. Bearing and journal surfaces must be smoothly polished to a surface having an error of not more than three to five millionths of an inch. The entire gear housing is of aluminum, to keep the assembly weight to a minimum. In spite of the huge amount of power the gear transmits, the theoretical tooth contact stresses are no higher than those normally encountered in other aircraft-type gears.

While jet propelled military fighter planes without propeller drives will probably remain supreme because of their tremendous speed, the geared gas turbine plane with propeller is expected to prove far more practical for some long range bombers and most commercial use.

# Properties and Limitations For Stepped and Tapered Extrusions

**W. H. ARATA**
Production Design Engineer, Lockheed Aircraft Corporation

**Two new types of extrusions are described; their limitations and advantages are discussed; and applications are cited. Tolerances and design data are given. The use of rolled billets is recommended for parts of sizes larger than those that can be made by the extruding process.**

INSIDE tapered extrusions and stepped extrusions are relatively recent developments. Stepped extrusions were originally developed to fulfill the need for blanks for spar caps that would require little machining. The advantages of forming metal parts by these methods, as well as the scope and limitations of the methods, are discussed here. Although the information has been checked against the latest extruding data, advancements have been so rapid that prospective users of these new type extrusions are advised to consult with an extruding company before basic design is carried to completion.

An inside tapered extrusion has uniform exterior dimensions and tapered interior dimensions. Fig. 1 illustrates the method of forming a hollow ingot into an inside tapered extrusion. Inside tapered extrusions are extruded on the same equipment as standard extrusions.

A stepped extrusion is actually two uniform sections made in one piece. As shown in Fig. 2, the smaller section leaves the die first. Split or removable dies are required to remove the extrusion. The larger section of a stepped extrusion, Fig. 3, is not limited by the length of the die, Fig. 2. The step can be made at any desired point along the length of the section so long as its position is compatible with the billet size and machining costs.

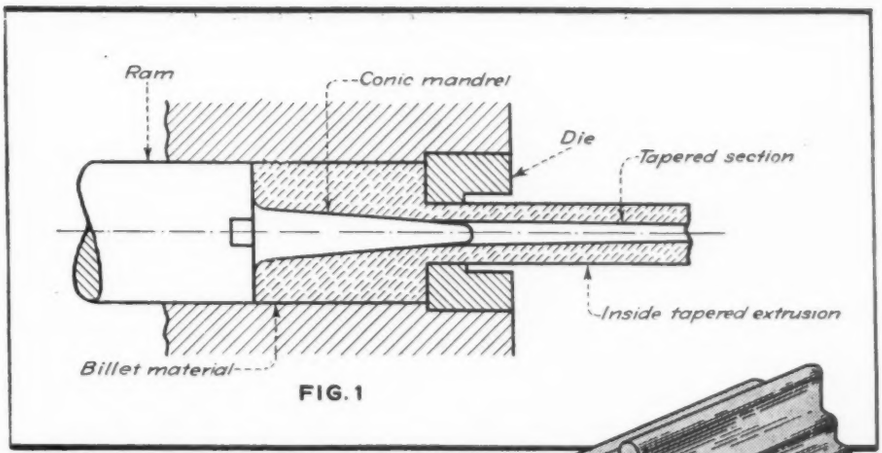



FIG. 1

**Fig. 1—A diagram showing how an inside tapered extrusion is formed from a hollow ingot.**

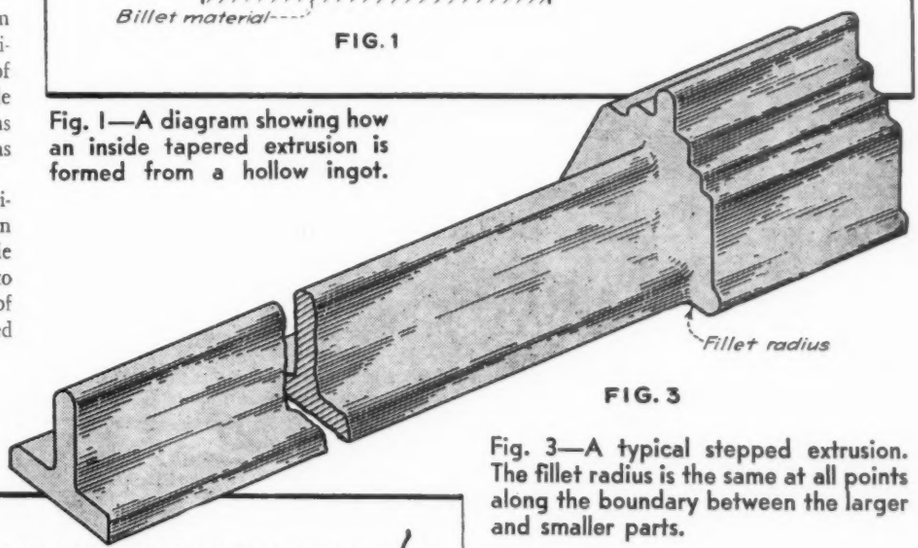



FIG. 3

**Fig. 3—A typical stepped extrusion. The fillet radius is the same at all points along the boundary between the larger and smaller parts.**

**Fig. 2—Diagram showing manner of making stepped extrusions. Split or removable dies are required.**

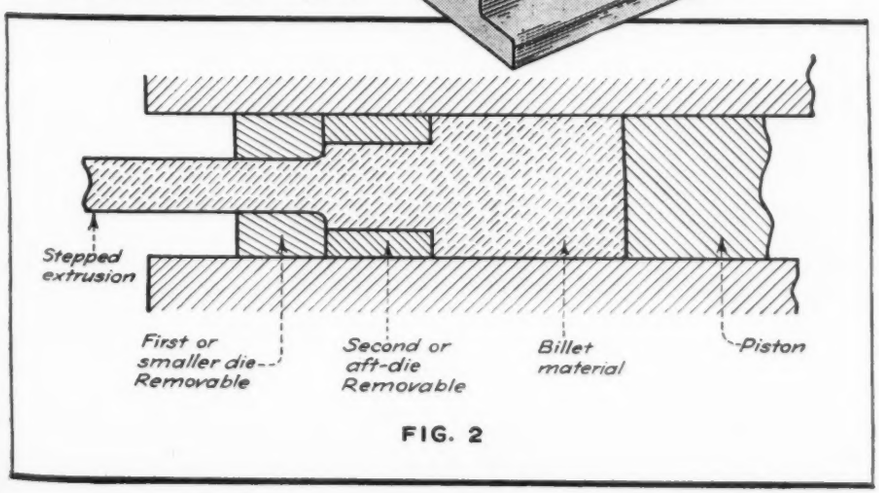



FIG. 2

The material commonly used for these extrusions is 24S-T aluminum alloy. Under most conditions the 75S-T and 14S-T alloys are also satisfactory. Table I contains data on average mechanical properties for these alloys. Although not commonly used for stepped and inside tapered extrusions, 17S-T and 53S-T are included to complete the tabulation of the extrudable aluminum alloys

**Table I—Mechanical Properties* (Longitudinal) of Aluminum Alloys for Extruded Parts**

| Alloy | Ultimate Tensile Strength, lb. per sq. in. | Tensile Yield Strength, lb. per sq. in. | Elongation in 2 in., Percent | Ultimate Shear Strength, lb. per sq. in. | Ultimate Bearing Strength, lb. per sq. in. |
|---|---|---|---|---|---|
| 14S-T | 60,000 | 50,000 | 7 | 36,000 | 90,000 |
| 17S-T | 50,000 | 32,000 | 12 | 30,000 | 75,000 |
| 24S-T | 57,000 | 42,000 | 12 | 35,000 | 85,000 |
| †24S-T8 | 64,000 | 55,000 | 5 | 39,000 | 96,000 |
| 53S-T | 32,000 | 25,000 | 10 | 22,000 | 48,000 |
| 75S-T | 78,000 | 70,000 | 6 | 47,000 | 101,000 |

*Typical or average values. Physical properties will vary according to section thickness as well as from sequence of heat-treatment relative to any machining or forming operations. †24S-T aged.

**Table II—Specifications of Aluminum Alloys for Extruded Parts**

| Alloy | Army-Navy Aeronautical Specification | Federal Specification | Navy Specification | Aeronautical Material Specification AMS |
|---|---|---|---|---|
| 14S-T | AN-A-8 | ..... | ..... | ..... |
| 17S-T | ..... | QQ-A-351 | 46-A-4 | 4151 (T) |
| 24S-T | ..... | QQ-A-354 | 46-A-9 | 4152 (T) |
| 53S-T | AN-A-11 | ..... | ..... | ..... |
| 75S-T | ..... | QQ-A-331 | 46-A-10 | ..... |

Notes: 1. Refer to appropriate specification for proper condition or temper callout.
2. Current revision letter for each specification not included in above table.

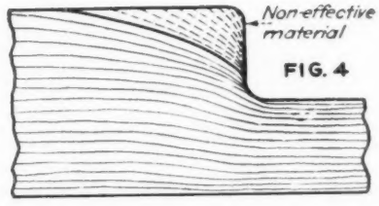



FIG. 4

Fig. 4 Grain structure at transition section of stepped extrusion.

**Table III—Chemical Composition of Aluminum Alloys for Extruded Parts, percent**

| Alloy | Al | Mg | | Si | | Fe | Cu | | Mn | | Zn | Cr | | Ti | Misc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min. | Max. | Min. | Max. | Max. | Min. | Max. | Min. | Max. | Max. | Min. | Max. | Max. | Total |
| 14S-T | Balance | 0.2 | 0.8 | 0.5 | 1.2 | 1.0 | 3.9 | 5.0 | 0.4 | 1.2 | 0.1 | .... | 0.10 | ... | 0.15 |
| 17S-T | Balance | 0.2 | 0.8 | ... | 0.8 | 1.0 | 3.5 | 4.5 | 0.4 | 1.0 | 0.1 | .... | 0.25 | ... | 0.15 |
| 24S-T | Balance | 1.2 | 1.8 | ... | 0.5 | 0.5 | 3.8 | 4.9 | 0.3 | 0.9 | 0.1 | .... | 0.25 | ... | 0.15 |
| 53S-T | Balance | 1.1 | 1.4 | 0.5 | 0.7 | 0.35 | ... | 0.1 | ... | 0.1 | 0.1 | 0.15 | 0.35 | ... | 0.15 |
| 75S-T | Balance | 2.1 | 2.9 | ... | 0.5 | 0.7 | 1.2 | 2.0 | 0.10 | 0.30 | 5.1–6.1 | 0.15 | 0.40 | 0.2 | 0.15 |

Note: The above chemical composition percentages reflect the requirements given in the specifications shown in Table II. Procurement specifications may vary composition content slightly depending upon issuing agency.

and to provide a comparison. Table II, in conjunction with Table I, gives the latest procurement specifications for the above-mentioned alloys. As a further aid in selecting the proper alloy, Table III is given, which shows the chemical composition of the aluminum alloys used for extruded parts and other applications.

Extruded shapes between 0.25 in. and 1 in. in thickness, as a general rule, show higher tensile strengths than either thinner or thicker sections of the same material. Static tensile and fatigue tests conducted by the Aluminum Company of America on transverse and longitudinal coupons of stepped extrusions, cut both from the small and the large sections, as well as from sections in the region of the step, have indicated that the strength of the material at the step is between the strength of the butt section and that of the smaller section. Except for the portion of the step indicated in Fig. 4, the strengths of stepped portions are comparable to the strengths of standard extrusions of like size and alloy.

**Table IV—Normal Extrusion Press Limitations for Aluminum Alloys**

| Factor | Basic Extruded Billet* | Finished Extrusion† |
|---|---|---|
| Weight | 350 lb. | 180 lb. for 8 in. dia. circle |
| Diameter | 12 in. (24ST and others)<br>10 in. (75 ST) | 240 lb. for 11 in. dia. circle |
| Length | ..... | 50 ft.‡ |

*Billet is the metallic charge inserted in the extrusion press.
†Loss in weight due to cut-offs of nose and butt billets from the basic billet.
‡Maximum length. Length is a function of cross-sectional area relative to weight of billet.

Lenth, cross-section, and weight are the primary size limitations. Table IV gives some common extrusion press limitations. Inside tapered and stepped extrusions more than 25 ft. long have been extruded successfully. Experimental use indicates a maxi-

mum weight of 350 lb. per extrusion prior to machining. Rolled billets are recommended for parts weighing more than 350 and up to 1,500 pounds.

INSIDE TAPERED EXTRUSIONS. The inside dimensions and taper, that is, the varying wall thickness, are functions of the mandrel design and the volume of billet used. The same limits regarding proportions and die projections apply for cross-sectional shapes of inside tapered extrusions as for standard extrusions. Tables V and VI supply these limitations. In order to hold the mandrel in its proper position as the part is being extruded, it is necessary to extrude symmetrical sections or sections where the pressure at the die opening is balanced. Table VII shows shapes suitable for inside tapered extrusions.

The outside configuration has no taper. It is constant and governed by the shape of the die. Tolerances on external dimensions are given in Table VIII. These are commercial extrusion tolerances.

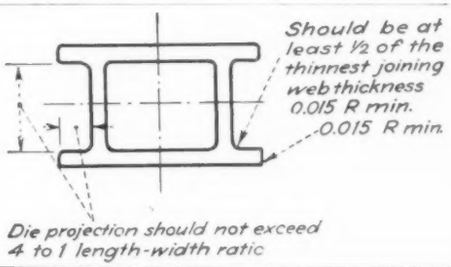
The tapered inside surface will be uniformly tapered with respect to the outside surface within a plus or minus tolerance of 15 percent relative to wall thickness for extrusions such as those shown in Fig. 5. On simpler extrusions a minimum wall thickness tolerance of plus or minus 10 percent of nominal can be held. This means that a 0.500 in. wall has an expected tolerance of plus or minus 0.050 inch.

The length of an inside tapered extrusion depends upon the billet weight and the cross-sectional area. The billet length is restricted by the space occupied by the mandrel, for mandrel length plus the billet length cannot exceed the length of the cavity.

One inch is the minimum practicable hole size. Change in degree of taper in the inside wall is possible. The change is incorporated in the design of the mandrel and an allowance should be made also in the size of the billet with which to charge the extruding press. Depending upon the cross-section, the cost of dies for inside tapered extrusions are

**Table V—Standard Minimum Extrusion Thickness**

| Alloy | Section Width in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Under 1 | 1-2 | 2-3 | 3-4 | 4-6 | 6-8 | 8-10 | 10-12 |
| 14S-T | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.141 | 0.187 | 0.250 |
| 17S-T | 0.050 | 0.062 | 0.078 | 0.109 | 0.141 | 0.156 | 0.187 | 0.250 |
| 24S-T | | | | | | | | |
| 53S-T | 0.040 | 0.050 | 0.063 | 0.078 | 0.094 | 0.109 | 0.125 | 0.125 |
| 75S-T | 0.100 | 0.125 | 0.125 | 0.125 | 0.125 | 0.188 | 0.375 | 0.437 |


Should be at least ½ of the thinnest joining web thickness
0.015 R min.
0.015 R min.
Die projection should not exceed 4 to 1 length-width ratio

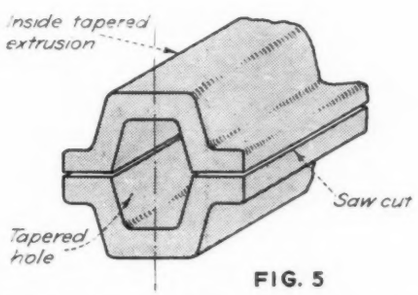



FIG. 5

**Fig. 5—Irregular shaped inside tapered tube can be split to form two tapered hat sections or four Z-shaped sections.**

**Table VI—Die Section Limitations**

| Tolerance on Corner And Fillet Radii | |
|---|---|
| Radii, in. | Tolerance |
| under 0.188 | ± 0.015 in. |
| 0.188 and over | ± 10 percent |

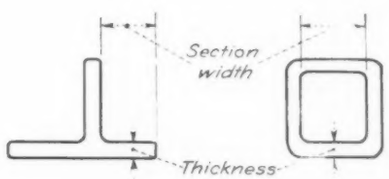



**Table VII—Shapes Suitable For Inside Tapered Extrusions**

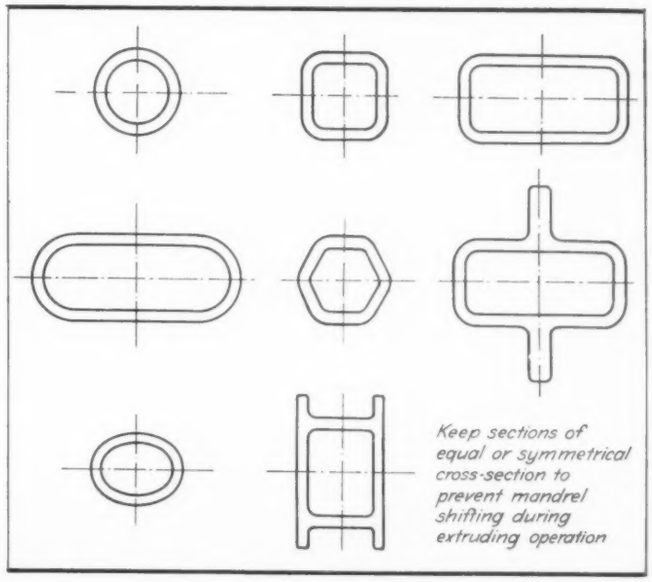
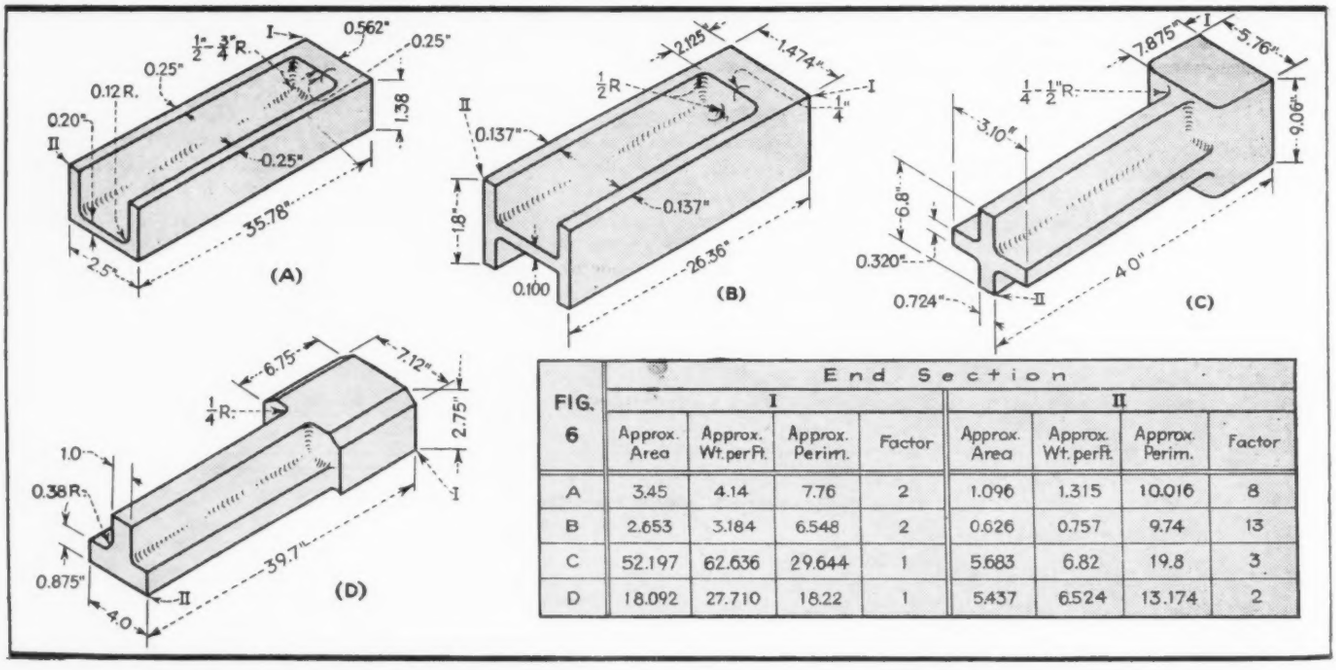



**Table VIII—Linear Dimension Tolerances for Heat-Treated Aluminum Alloy Extruded Parts**

| Dimension, in. | Tolerance Plus or Minus, in. | Tolerance on dimension where metal on leg is ⅛ in. thick or less or projects more than 2 in. |
|---|---|---|
| up through 0.125 | 0.010 | 0.020 |
| 0.126 " 0.500 | 0.015 | 0.030 |
| 0.501 " 1.000 | 0.020 | 0.040 |
| 1.001 " 2.000 | 0.025 | 0.050 |
| 2.001 " 3.000 | 0.030 | 0.060 |
| 3.001 " 4.000 | 0.035 | 0.060 |
| 4.001 " 5.000 | 0.040 | 0.090 |
| 5.001 " 6.000 | 0.045 | 0.090 |
| 6.001 " 7.000 | 0.050 | 0.110 |
| 7.001 " 8.000 | 0.055 | 0.110 |
| 8.001 " 9.000 | 0.060 | 0.130 |
| 9.001 " 10.000 | 0.065 | 0.130 |
| 10.001 " 11.00 | 0.070 | 0.160 |
| 11.001 " 12.000 | 0.080 | 0.160 |

Closer tolerances will markedly increase costs.




| FIG. 6 | End Section I | | | | End Section II | | | |
|---|---|---|---|---|---|---|---|---|
| | Approx. Area | Approx. Wt. per Ft. | Approx. Perim. | Factor | Approx. Area | Approx. Wt. per Ft. | Approx. Perim. | Factor |
| A | 3.45 | 4.14 | 7.76 | 2 | 1.096 | 1.315 | 10.016 | 8 |
| B | 2.653 | 3.184 | 6.548 | 2 | 0.626 | 0.757 | 9.74 | 13 |
| C | 52.197 | 62.636 | 29.644 | 1 | 5.683 | 6.82 | 19.8 | 3 |
| D | 18.092 | 27.710 | 18.22 | 1 | 5.437 | 6.524 | 13.174 | 2 |

Fig. 6—Representative stepped extrusions with approximate dimensions and fillet radii for use in die design.

two to three times the cost of conventional extrusions dies.

A 3 deg. tolerance between the major and minor axis of the inside dimension with the major and minor axis of the outside dimensions (i.e. orientation of tapered hole with respect to the outside surface of the extrusion) is required for parts like the one shown in Fig. 5. The thinner the wall, the greater the tendency of the extruding pressures to equalize with the mandrel, thus tending toward less twist. Refer to Table IX for straightness tolerances.

The inside and outside surfaces of an inside tapered extrusion are comparable to typical aluminum extrusions and relatively free from deep lines and scratches. Quite often, as an additional step to save weight, inside tapered extrusions are machined on a milling machine. When designing templates for the milling machine, allowance must be made for the extrusion wall thickness tolerances. The probability of warp and twist resulting from the machining of thin wall sections must also be considered.

Stepped Extrusions. The larger section must completely circumscribe the smaller section. Although desirable, it is not necessary for the two parts of a stepped extrusion to have a common base. This makes fewer directions for metal flow during extruding. At present, stepped extrusions are made with only one step and with the section reduced in only one direction.

Stepped extrusions can be combined with inside tapered extrusions. The large end of the tapered hole must be at the butt end and the hole must extend through it.

Fillet radii at the step are necessary. They should be equal in all planes normal to the cross sections at the step. Fig. 6 gives radii used for the particular shapes. These values should be followed in determining die design. Die construction does not permit the use of large tapering fillets. Gradual changes in cross section instead of fillets are uneconomical because they must be machined into the extrusion. Die construction for stepped extrusions also prohibits the great variety of wide, thin flanges, commonly available on commercial extruded parts. Refer to Table X for angular dimension tolerances.

An allowance of 0.125 in. for machine finishing of large stepped extrusions is recommended to compensate for mismatch and straightening, see Fig. 7. An allowance of 0.06 in. is sufficient for machine finishing of small stepped extrusions. Smaller allowances may not provide sufficient material for machining to designed dimensions because the parts of a stepped extrusion often depart from alignment because of the factors in forming, heat-treating, and stretching.

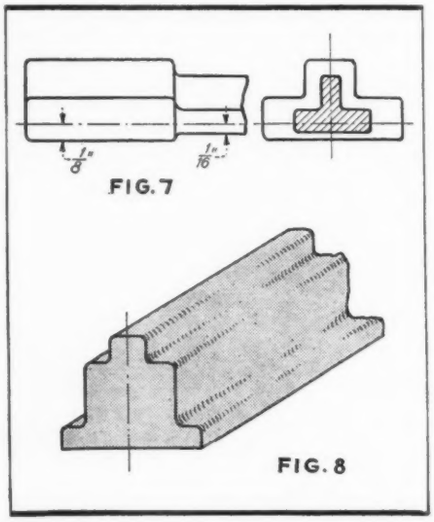



Fig. 7—Tolerances applicable to the stepped section of a stepped extrusion. Fig. 8—Billet for a single beam cap prior to any machining.

**Table IX—Straightness Tolerances For Inside Tapered Extrusions**

| Length | Tolerance |
|---|---|
| up to 5 ft. | 1/16 in. bow |
| 5 to 10 ft. | 1/8 in. bow |
| over 10 ft. | 1/4 in. bow |

**Table X—Angular Dimension Tolerances for Heat-Treated Aluminum Alloy Extruded Parts**

| Leg | | Tolerance plus or minus, deg. |
|---|---|---|
| Length, in. | Thickness, in. | |
| up to 1 in. | Up to 0.125 | 2 |
| Over 1 in. | Up to 0.125 | 3 |
| over 1 in. | 0.126 to 0.187 | 2 |
| over 1 in. | Over 0.187 | 1.5 |

Rolled Billets. Parts that are too large for fabrication as extrusions often can be made from rolled billets. A 14S ingot is hot rolled into a billet having sufficient cross-sectional shape to permit the fabricating of the part from the billet. After rolling it is heat treated and straightened.

The billet is designed to achieve the desired structural characteristics and at the

same time having stock such that the attaching fitting can be machined integral with the simulated extruded cap section, which is finished to size on a spar mill. Fig. 8 illustrates a billet for a single cap.

Quite often the original billet may be so designed as to allow the fabrication of two caps from a single billet, the billet being only slightly larger than one required for a single cap. The utilization of raw material, by splitting lengthwise, is shown in Fig. 9. The cross-sectional area is approximately 29 square inches.

The Model B-17 airplane used 304 in. inside tapered 24S-T aluminum alloy extrusions of square cross section as wing spar chords. These spar chords are extruded with a circular cross section and are then drawn to the round cornered square having an exterior radius at the corner of 0.75 in. The minimum wall thickness at the large end of the taper is 0.125 in. The wall thickness at the other end is 0.500 in. The spar chord weighs about 77 pounds. The constant outside width is 2.68 inches.

Tapered angles can be made by cutting inside tapered square or rectangular tubes. Figs. 10(A) and 10(B) illustrate two ways of splitting the tube. Tapered hat sections are produced by cutting an inside tapered extrusion in half. See Fig. 5. Quite often such sections are machine tapered on the outside after the basic extrusion has been cut in half. Resultant distortion from the machining of thin sections must be avoided. Inside tapered extrusions, similar to the one shown in Fig. 5, have been designed weighing 242 lb. and having a basic length of 240 in. for use as skin supporting stringers.

Stepped extrusions are being used instead of both hammer-forged blanks for attachment fittings and sheet metal hat sections primarily because the parts can be fabricated from stepped extrusions at lower costs. Industrial uses of stepped extrusions, though in its infancy, include pre-shaped forgings and blanks for machining. Fig. 6 gives shapes that can be expected from stepped extrusions. Longer extrusions of these shapes are practicable. The factors shown in the table of Fig. 6 are a "rule of thumb" measurement of the section shape and are used to gauge the price of the extrusion. The factor for any extrusion is determined by dividing the perimeter in in. by the weight per ft. in pounds.

The advantages of one type of construction over another are evaluated to a large degree in terms of total cost of production. Designers specify one type in preference to another because of savings in material and labor costs. Thus studies and comparisons of actual production costs are essential to a full appreciation of the advantages. Shop costs differ with different companies so that a less costly method for one manufacturer may not prove less costly to another. Such intangibles as handling facilities, rejection rates, and sequences of assembly should be balanced in with the real costs.

In conclusion, the following general advantages can be cited. The integral construction of stepped extrusions and rolled billets have fewer parts, which often weigh less than built-up parts. Although machining is usually required, there are fewer assembly problems for final installation. The hollow extrusion with the taper on the inside simplifies the assembly problem because the mating parts are not affected by the taper.

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2. "Stepped Extrusions," K. F. Thornton, Mech. Eng. 7-44.
3. "Milling Douglas Spar Caps from Integral-Eye Rolled Billets," N. A. Lombard and G. R. Gwynne; Machinery, July, 1944.
4. "The Development of Spar Caps with Integral Fittings," J. F. Schirtzinger; 1944 SAE paper.

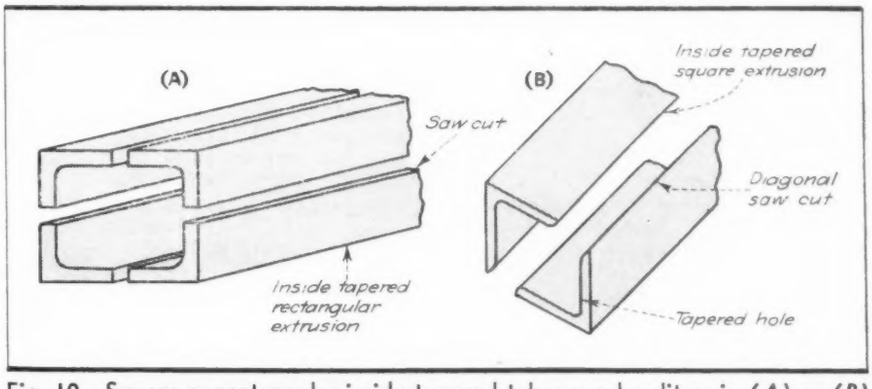




**Fig. 10—Square or rectangular inside tapered tubes can be slit as in *(A)* or *(B)* to obtain tapered angles.**

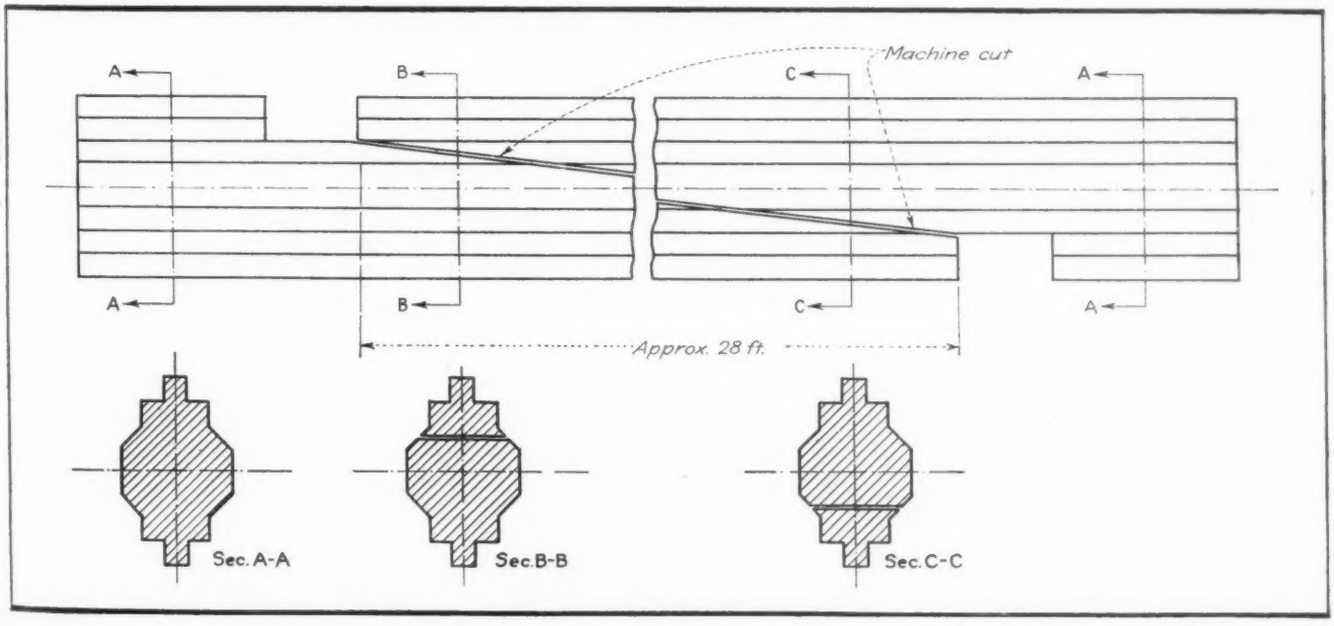



**Fig. 9—A diagram showing how a rolled billet can be cut into two tapered parts.**

# INDUSTRY AND SOCIETIES

**RESEARCH—STANDARDS—PATENTS**

## Naval Research Laboratory

### Its Contributions to War and Peace are Reviewed

THE NAVAL RESEARCH LABORATORY, located on the Potomac River in Anacostia, Washington, D. C., had its origin in the work of the Naval Consulting Board, which was formed during the first World War. Spark-plugged by Thomas Edison, this Board had foreseen the need for a group whose sole mission was to adapt scientific advances to the improvement of the Navy. The Naval Research Laboratory has been working toward that end since its establishment in 1923.

The main plant of the Laboratory is spread over an area of 58 acres. It consists of nearly fifty buildings, used as laboratories, shops, and barracks for service personnel.

Research functions of the Laboratory are not confined to engineering and specific military applications; they include research in the basic sciences as well. This is shown in the organization of the Laboratory, which includes the following major divisions:

Airborne Radio
Aircraft Electrical Research
Chemistry
Electronic Special Research
Fire, Missile and Pilotless Aircraft
Mechanics and Electricity
Metallurgy
Physical Optics
Ship-Shore Radio
Sound

There are also service activities such as the Radio Material School, the Airborne Coordinating Group, and the Electronic Field Service Group. Among the facilities provided for the technical divisions are a machine shop, foundry, woodworking shop, and drafting room. At present, the total number of employees is approximately 5000, of whom about half are civilians and the remainder Naval personnel.

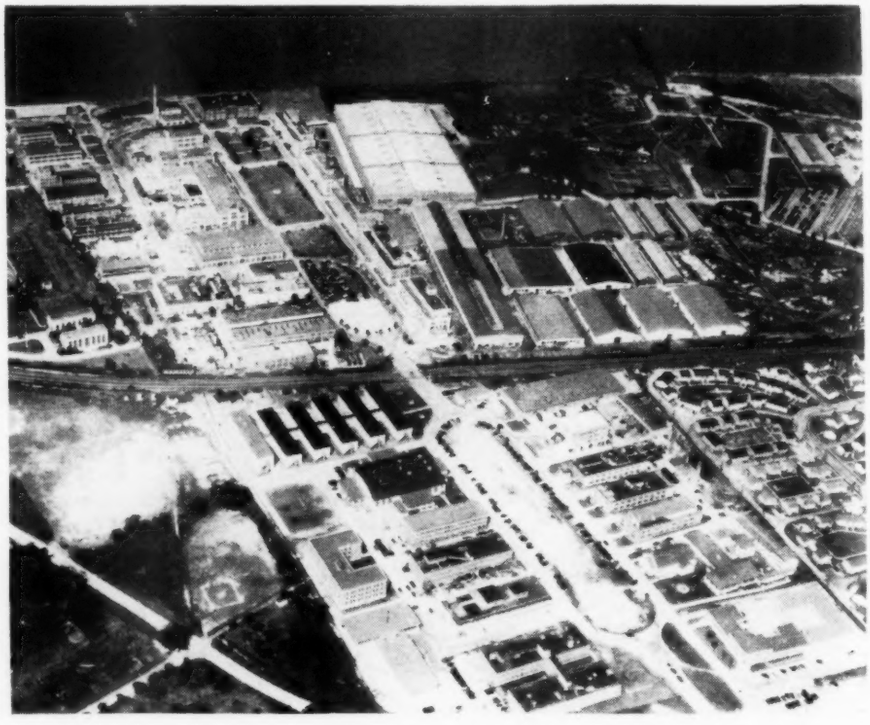
#### War Contributions

It is not generally known that the Naval Research Laboratory initiated one of the first methods for separating U-235 from U-238 for the production of atomic energy.

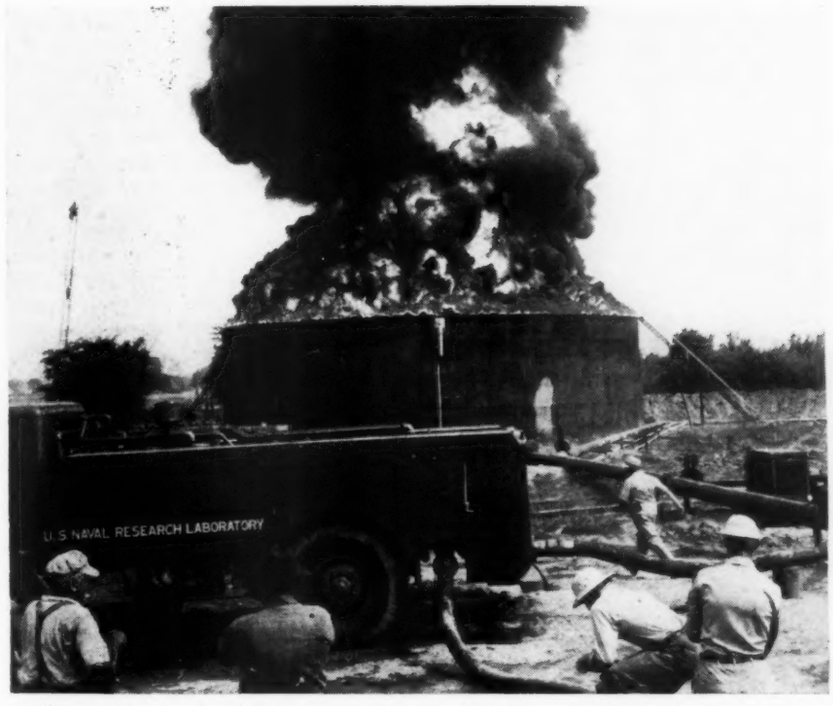
Dr. Ross Gunn of NRL, who had been interested in "atom-splitting," in March, 1939 became convinced that atomic energy was a possibility in the near future. The Navy's Bureau of Engineering was interested in the project, not as an explosive but for ship-propulsion, and allotted $3,000 to start the project.

Dr. Philip H. Abelson of the Carnegie Institution had been working on an apparently practicable method for securing a concentrate of U-235. In 1940 NRL made arrangements to finance his efforts, and later moved him and his apparatus to Anacostia. The Gunn-Abelson method, called "thermal diffusion", actually produced U-235 in small quantities from a pilot plant constructed in the Laboratory in 1942 and 1943. In December, 1942 NRL turned over all information and patents to Major-General Groves, in charge of the Manhattan Project. A year later NRL started building a larger pilot plant at the Philadelphia Navy Yard, which was completed at a cost of $2,000,000. In 1944 the Manhattan Project took the Philadelphia pilot plant as a model for construction of a similar plant at Oak Ridge, Tennessee.

NRL's interest in radar goes back to 1922 when Dr. A. Hoyt Taylor and Leo C. Young observed the disturbance in radio waves caused by a passing steamer. Taylor and Young continued their work unobtrusively, and in 1930 it was discovered that an aircraft could be similarly detected. The possibilities of detection by radiation so interested the Bureau of Engineering that its Chief, Rear Admiral Bowen, sponsored a research project in 1935, and since that time Radar research has been an ever expanding phase of NRL's activities. Dr. R. M. Page of NRL solved the problem of designing a transmitter and receiver that could be placed in the same ship. In April, 1937 the XAF model radar was proved at sea, and by 1939 it had been thoroughly tested in battle maneuvers. On Pearl Har-



Aerial photograph shows laboratories and shops of the Laboratory.




**Million-gallon tank oil fires were extinguished in several minutes at a recent test at Findley, Ohio, using chemical materials and equipment developed at the Naval Research Laboratory for fighting oil fires.**

**The supersonic interferometer is used to measure velocity of sound waves in liquids, between —10 and +100 deg. C.**

bor day, there were 20 units in operation on selected vessels familiar with the tactical and navigational employment of the new device.

NRL developed the first Radar submarine antenna which enabled the sub to rise to periscope depth and search for aircraft before emerging. This set was merely a warning device, as it was non-directional. It then became a danger, as it was a magnet which quickly attracted hostile air attack. NRL then perfected a directional radar antenna for use with Western Electric Radar System. This set was so effective that it could be used as a fire-control instrument and several Japanese ships were actually torpedoed without being seen. Beneath the surface, Sonar performs the same functions as does Radar in the atmosphere, and the principle of operation is parallel. Sound waves are emitted from a submerged "transducer", they "bounce" back from an obstacle, and are picked up again by the transducer.

The Chemistry Division developed a rain-repellent film which is sprayed on glass surfaces. It has proved more effective than windshield wipers and can be used on the curved surfaces of greenhouses, bomber noses and blisters where wipers would be impractical. Even more important was the successful production of a fireproof and low-freezing hydraulic fluid. Most designers prefer hydraulic control systems to electric, but they had avoided the use of liquid systems in military planes because of the fire hazard and because of frequent failures at extreme altitudes due to freezing.

As a result of this development, most Naval aircraft are designed with hydraulic systems. The Chemistry Division also shared in the development of self-sealing gasoline tanks.

Other wartime developments credited to the NRL are: microwave anti-submarine radar, under water sonic detectors, the Sono-Radio Buoy, magnetic buoys, a non-reflecting lens coating for optical instruments and countless radio transmitters and receivers for specialized purposes.

## Peacetime Applications

Although many of the developments of the NRL during the war can be applied to peacetime uses, there are a large number which promise to find immediate application in industry. Some specific examples follow.

The Navy's need for piezoelectric crystals in Sonar gear resulting in a new method of producing crystals. Early in the war, a new crystal, ammonium dihydrogen phosphate, was demonstrated by the Brush Development Co. and adopted by the Navy. A group of the Laboratory's scientists were assigned the job of helping to get the new crystal into production and to measure the properties essential to the most efficient design of projectors. Cooperating with industry, enough of the technical problems were solved that projectors using the new crystal were being constructed on a large scale within approximately a year.

The properties of the new crystal are more constant with temperature and it is chemically stable within the temperature ranges encountered in service. They will withstand enough power to generate cavitation in the water without danger to the crystal burning out, so that the crystals are no longer limiting factor in the range of Sonar devices. The increased power handling capacity and temperature stability have made possible the design of a variety of more dependable piezoelectric devices including vibration pickups, blast gauges, interferometers, phonograph pickups and hearing aids.

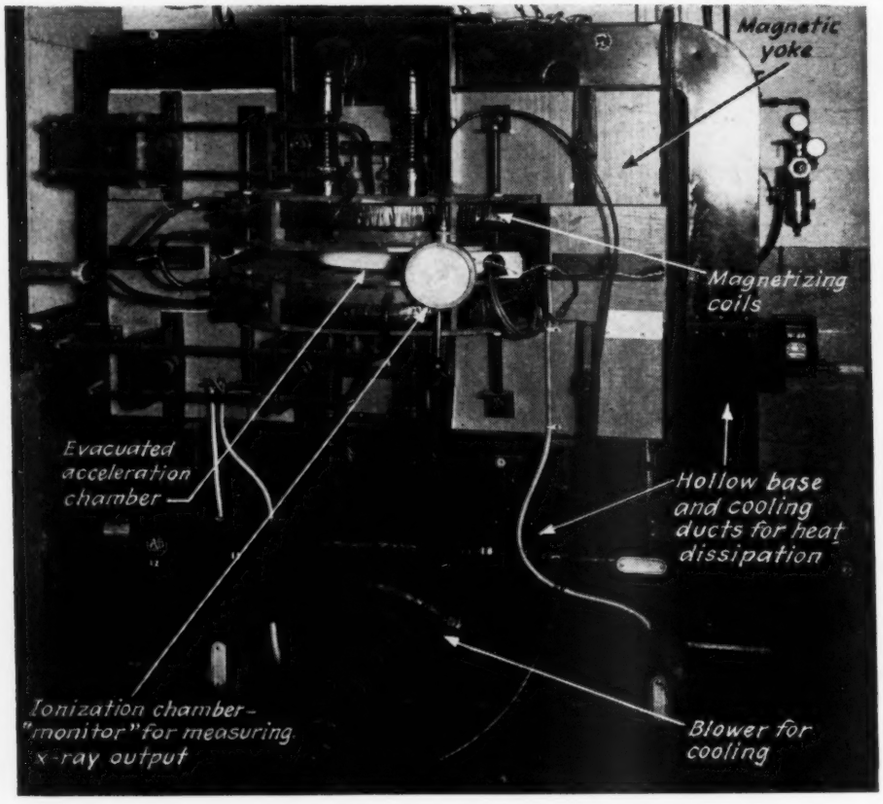
A similar problem is the supply of quartz for oscillator control. The inherent mechanical strength and the small variation of the properties of quartz with temperature make satisfactory replacement by a softer, water soluble crystal very unlikely.

An investigation of the character of the "twinning" that excludes all but a small fraction of natural quartz from use as oscillators has been made to determine the possibility of using portions which are now discarded. A method recently developed by NRL now appears very promising for the removal of electrical twinning at least for those plates oriented in the "cut" most useful to the Navy. Successful large scale development of this process could probably double the usable quantity of natural crystals.

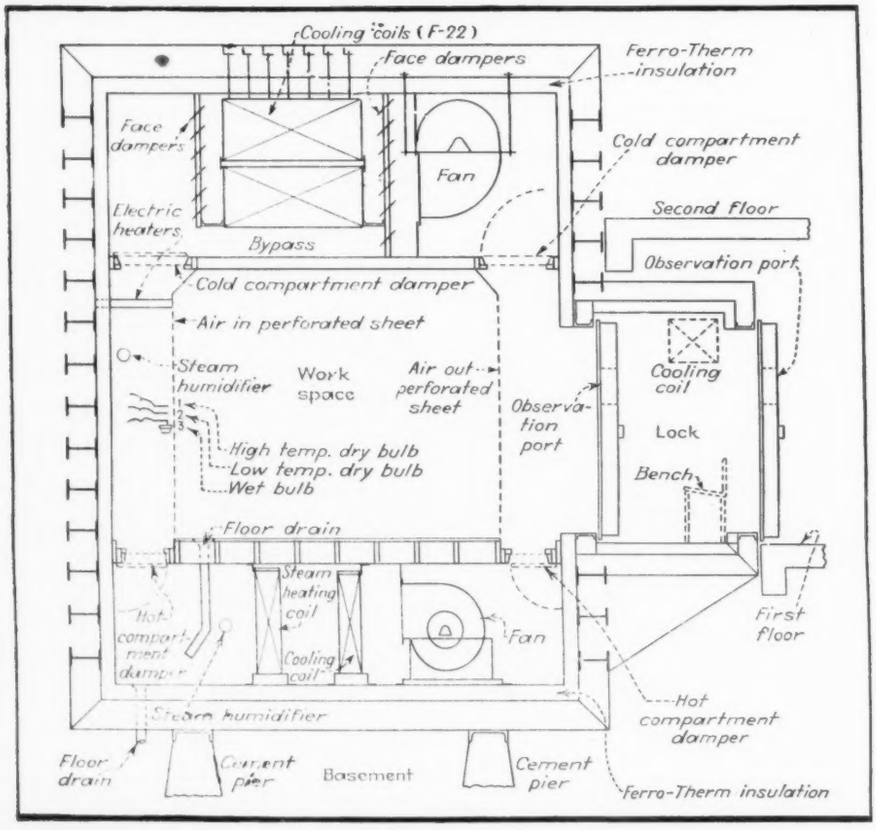
The possibility of growing quartz synthetically is also being investigated, and methods of growth by hydrothermal synthesis have been developed with which it is planned to grow not only quartz, but the other mineral-like piezoelectric materials as well in search for a crystal which can extend the range of high frequency control.

## Altitude Test Chambers

Another line of research at the NRL, illustrating extension of the limits of environment, is seen in two of the several altitude


Magnetic yoke
Magnetizing coils
Evacuated acceleration chamber
Hollow base and cooling ducts for heat dissipation
Ionization chamber - "monitor" for measuring x-ray output
Blower for cooling

**Betatron at NRL is used for inspection of thick metallic sections and for X-ray studies. Equipment shown above was developed at the Naval Research Laboratory.**




**Altitude chamber at Naval Research Laboratory simulates rapid changes in pressure, temperature and humidity, which are experienced by aviators.**

chambers at the Laboratory. The first altitude chamber, shown in the drawing, produces temperatures between —105 deg. F. and +170 deg. F., humidities between 15 and 95 percent for wet bulb temperatures of +35 deg. F. to +102 deg. F. and altitudes up to 70,000 feet.

The rapid rate at which conditions may be changed make this chamber the Laboratory's foremost piece of environmental equipment. Representative of its rapid change characteristics is a simulated climb from sea level and +49 deg. F. to 35,000 feet altitude and —70 deg. F. in seven minutes, and the return dive to sea level and +140 deg. F. in only 40 seconds. The principle of operation is storage of refrigerating and heating capacity in the compartments which can be isolated for this purpose. Test facilities include electrical connections for a wide range of current characteristics; two high-speed shafts through the chamber walls for driving aircraft generators inside the chamber and a huge motor operated door for entrance of large test equipment.

The second or "Blast-Cooled Test Chamber" is designed for testing aircraft generators, particularly in connection with brush problems. Temperature, humidity and altitude conditions to which the generator is subjected in actual use may be duplicated. The chamber can attain temperatures between —85 deg. F. and +180 deg. F. and altitudes to 80,000 feet. Humidities to 95 percent R. H. can be maintained above a 35 deg. F. dew point. Blast cooling air can be furnished at temperatures from existing ambient to 65 deg. F. By means of the air dryer, even air at ambient temperatures may be dried to a —80 deg. F. dew point.

## New Materials and Equipment

Contributions of the Chemistry Division to industry have also been considerable. A few of these are: 1. A foam-producing apparatus for extinguishing oil fires. This method, which both cools and smothers, has proved more effective than pre-war devices in extinguishing oil-tank fires; 2. A lining for concrete which makes possible the storage of gasoline in concrete tanks; 3. Several synthetic non-petroleum lubricating oils and greases which, for special purposes, exceed the efficiency of petroleum-base products. As an example, one of these oils makes possible the operation of electric motors at very high temperatures, in turn making practicable the production of lighter and smaller motors without reduction of horsepower; 4. A shark repellent, found very useful by fishermen, because it keeps sharks from tearing their nets; 5. Previously mentioned is the non-flammable and low freezing hydraulic fluid. This can be used to increase the safety and temperature range of any machine which uses a liquid power-train; 6. Investigation of the dielectric qualities of various liquids and the invention of a meter for measuring the dielectric impedance of the liquid. By placing this meter in a pipe, the presence of water in oil or gasoline, for instance, can be detected immediately; 7. Oxygen rebreathers and air analyzers, developed for use in submarines and high altitude aircraft, can be put to practical use in deep mines and by fire departments.

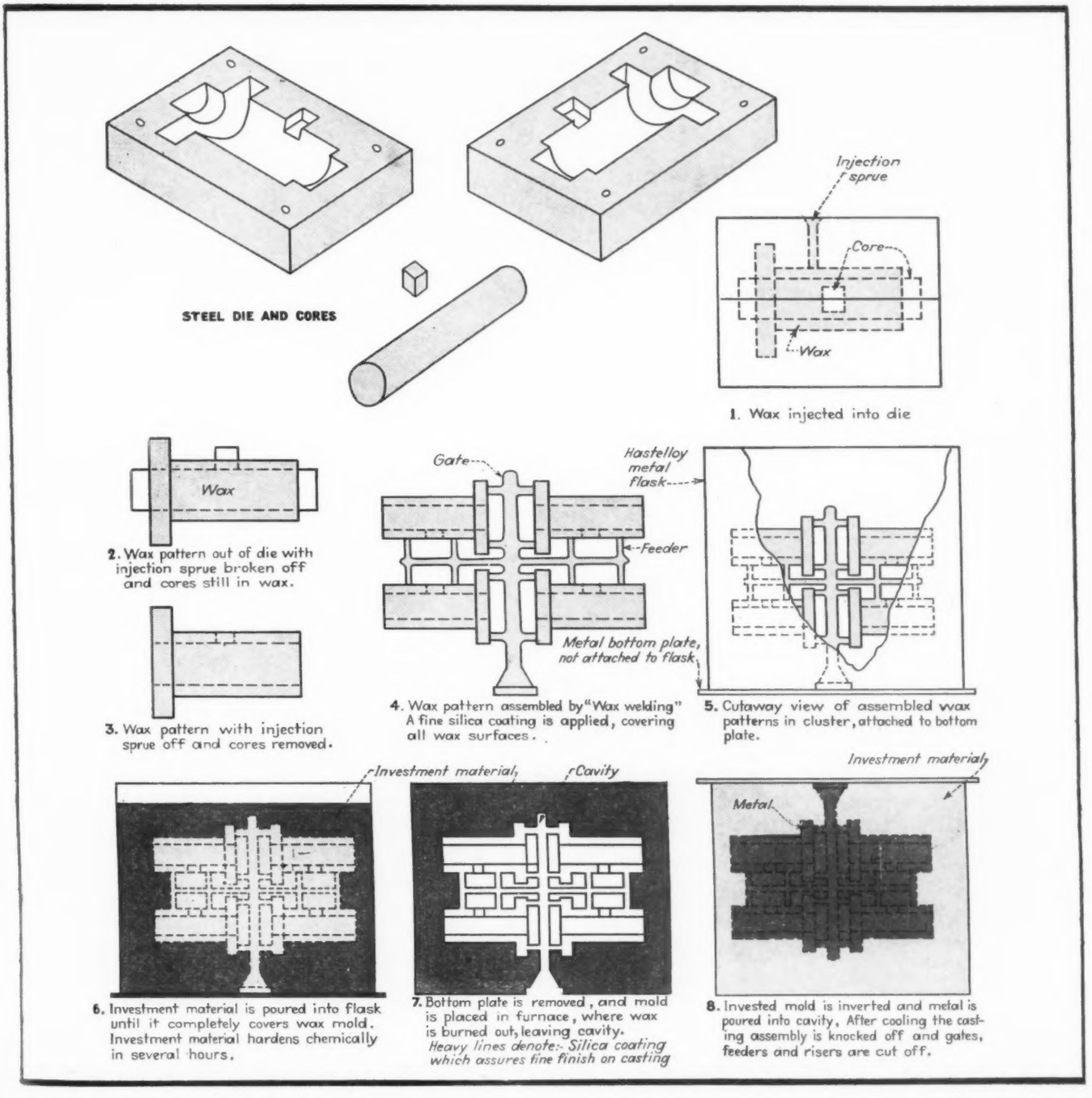
# Precision Casting Comes Of Age

GRADUATING FROM DENTISTRY TO INDUSTRY, the "lost wax" process of casting has come to the attention of engineers as a method of increasing flexibility in design of machine parts. Proponents of this method claim that parts with shapes too intricate to machine or forge economically, or those made of the war-born "super-alloys" too tough to form or finish by conventional methods, can be cast to tolerances of 0.003 in. or less, leaving a dense and strong internal structure, strong thin sections, and a surface that requires practically no finishing.

Most dramatic example of intricate parts made by precision casting are turbine blades for jet engines, including those of the much-publicized P-80 plane. But precision casting is finding increasing use in the production of such everyday industrial parts as bushings, gages, pump impellers, injector nozzles, multiple dies, scale pivots, valves, reciprocating slides, shoe sole and heel molds, textile machine parts, wearing plates, cathode mandrels, "squirrel cages" and cutting tools.

Although precision castings have been made to some extent with metal and plaster molds, the lost-wax method is gaining in prominence. Known more than 2,000 years ago by the ancient Chinese, this technique became important in the 1930's in the making of dentures and jewelry. It can now be used with both low and high melting point alloys. Patents on the investment material and some of the equipment used in the process are held by Austenal Laboratories, Inc., and the Haynes Stellite Company, a division of the Union Carbon and Carbide Corporation.

Shown in the accompanying drawings are the basic steps in the precision casting process. The molds shown at the top of the diagram are soft metal dies prepared from a master pattern. Then, necessary cores are placed in the die and wax is injected into the

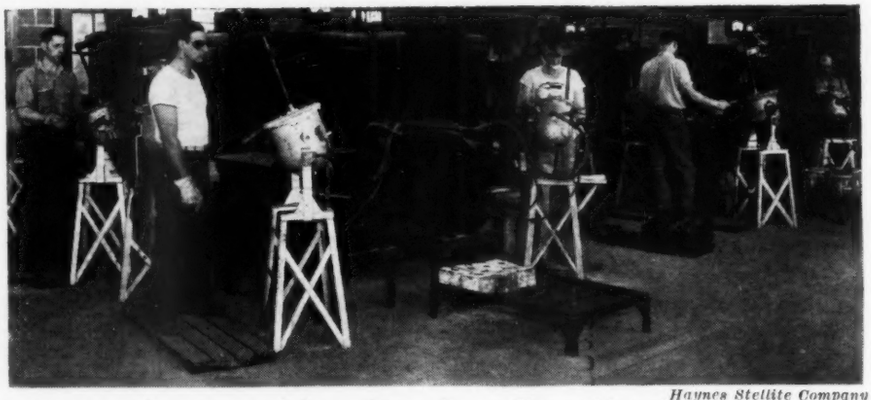

STEEL DIE AND CORES
Injection sprue
Core
Wax
1. Wax injected into die
Wax
2. Wax pattern out of die with injection sprue broken off and cores still in wax.
3. Wax pattern with injection sprue off and cores removed.
Gate
Hastelloy metal Flask
Feeder
Metal bottom plate, not attached to flask
4. Wax pattern assembled by "Wax welding" A fine silica coating is applied, covering all wax surfaces.
5. Cutaway view of assembled wax patterns in cluster, attached to bottom plate.
Investment material
Cavity
Investment material
Metal
6. Investment material is poured into flask until it completely covers wax mold. Investment material hardens chemically in several hours.
7. Bottom plate is removed, and mold is placed in furnace, where wax is burned out, leaving cavity. Heavy lines denote: Silica coating which assures fine finish on casting
8. Invested mold is inverted and metal is poured into cavity. After cooling the casting assembly is knocked off and gates, feeders and risers are cut off.

die by means of a "gun" which is inserted in the die and emptied by a pneumatic ram. The wax pattern is then removed from the die and any cores that are used also are removed. The wax gate is manually broken off. Operators in the assembly line inspect the wax patterns as they move by on a conveyor belt. The patterns are then assembled to gates and risers by "wax welding," and are mounted on wax hubs molded especially for the purpose.

The assembly is then dipped in a fine silica suspended in a suitable medium. This is responsible for the smooth finish of the castings, since this coating will later be on the mold surface which is adjacent to the molten metal. After the dipping operation, the pouring end of the wax assembly is mounted on a square steel base. The area not coated by the dipping process is then sprayed with silica. Somewhat coarser grains of silica are then screened or "stuccoed" to the dip coating. The assembly is then carried through a drying tunnel by conveyor belt.

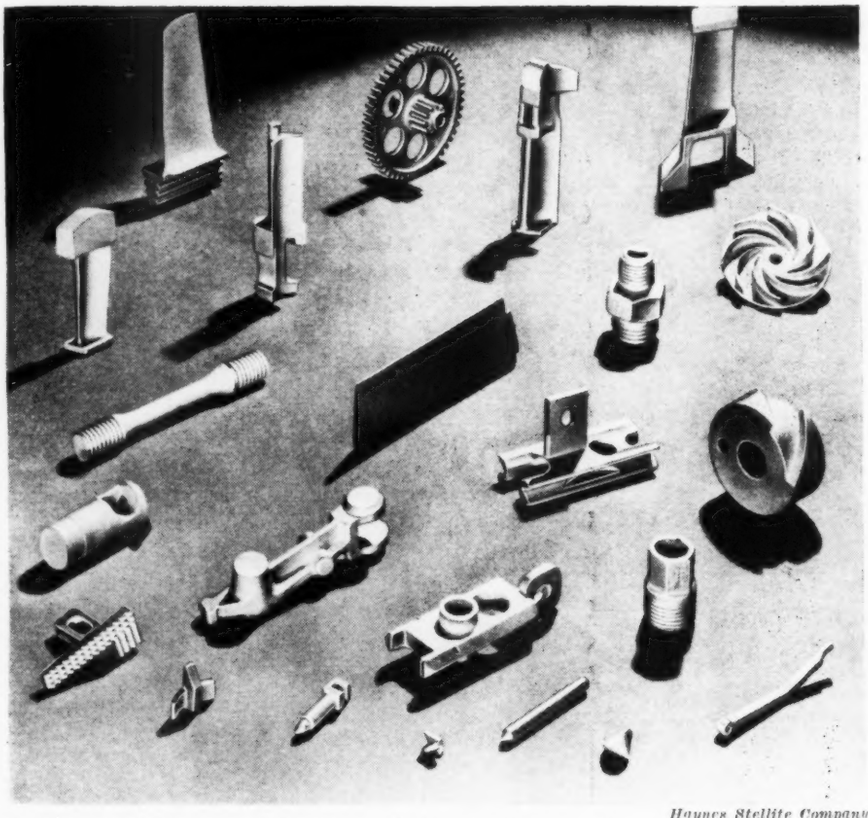
When the wax assembly has passed through the dehumidifying tunnel, a Hastelloy flask is sealed to the steel plate with wax, to make sure it is liquid tight. The flask is then filled with a chemically-hardening investment material. After the mold is filled, it is placed on a "shaker table." The vibration packs the investment material tightly around the assembly and eliminates all air. The investment material sets in about one hour. The excess investment material is cut off with a power saw and the mold is allowed to age for several hours. The steel plate is knocked off, exposing the pouring mouth into which the metal will be poured.

The molds are then placed upside down in a continuous furnace, where the wax is melted out. The process takes several hours, and temperatures reached are from 1300 to 1900 deg. F., depending on the part being produced. Meanwhile, the alloy to be cast is being melted in an electric furnace. The baked mold is inverted and clamped on the furnace, directly over the pouring spout. The metal is poured by inverting the entire furnace, and air pressure is turned on. The air pressure makes possible the casting of thin edges and makes the metal dense. The mold is allowed to cool slowly. After four hours the entire casting assembly is knocked from the mold. The excess investment material, gates and risers are removed, and the castings are then finished and inspected.



*Haynes Stellite Company*

**Indirect arc furnaces used for melting alloys. The mold is clamped directly on the furnace which is then inverted, and the metal is poured directly into the mold.**



*Haynes Stellite Company*

**A representative group of parts made by precision casting. Included are gears, jet propulsion blades, cams, pump impellers and spray nozzle parts.**

## Britain Plans Industrial Design Exhibition

BRITISH INDUSTRIAL DESIGN will be put on display in an exhibition that promises to be Britain's greatest industrial event in 1946. Sponsored and financed by the government's Council of Industrial Design, the exhibition will be held at the Victoria and Albert Museum in London, and will open on September 24. Britain hopes that she can convince the world through this exhibition that the standards of her design are up to the quality of her products.

This exhibition, to be called "Britain Can Make It," is being organized on a comprehensive, national scale to include all types of consumer goods, together with certain kinds of civil transport. The policy will be to select for exhibition only the best that modern British industry is producing. Exhibits will, in the main, consist of new postwar designs, but good designs which emerged just before the war and which are again going into production will not be excluded.

Space will not be sold. There will be no exhibits representative of individual firms, trade associations, or regional industrial groups. All necessary information will be given to visitors by attendants, who are employees of the Council. Each commodity will be presented according to one or more of three categories: (1) in commodity groups, either in specially designed settings or in separate halls; (2) in a series of 24 rooms, each to represent a different type of household rooms; (3) special features that tell a story, such as packaging or children's furniture. The name of the manufacturer, and where possible the designer, will be published, except where an industry objects to this practice.

# WASHINGTON NOTES

## Flurry of Patent Legislation Slated for Congressional Action

The announcement that the search room of the United States Patent Office is to be kept open twenty-four hours a day brings with it the realization that patent activity in the United States has reached the greatest heights in the history of the Patent Office. Overcrowded and inadequate facilities in the Patent Office have become a byword in Washington. Not helping the situation any has been the general dissatisfaction with our present patent system. Groups from all walks of life have expressed their discontent with the operation of our present patent machinery.

Until recently, the patent situation has been like the weather—most people talked about it, but few were willing or able to do anything about it. Among the latter is Casper W. Ooms, new patent commissioner (see November "Washington Notes" column). Besides acting as a new broom in the Patent Office, where he is making strenuous efforts to streamline patent procedures and eliminate outmoded practices, Mr. Ooms is actively pushing legislation which he feels will go far toward bringing our antiquated patent system up to date.

**Three Important Patent Bills**—Three bills are being most actively supported by Mr. Ooms. Following is a summary of these bills, together with their present status (names in parentheses are members of Congress who introduced the bills):

H. R. 4080 (Rep. Boykin) would attempt to speed up Patent Office procedures, now sadly behind schedule, by providing additional personnel for the Patent Office, and by authorizing the Commissioner of Patents to designate examiners to serve as examiners-in-chief. The latter action would permit these examiners to serve on the Patent Office board of appeals, allowing the appeals process, now about one year behind, to be materially speeded up. This bill has passed the House, the Senate patents committee, and is now awaiting consideration by the Senate.

H. R. 3756 (Rep. Boykin) requires the recording in the Patent Office of agreements relating to patents. This bill has passed the House and is now before the Senate patents committee.

H. R. 3757 (Rep. Boykin) provides for the public registering of patents available for licensing. It is felt by many that this bill will protect the inventor who is not familiar with markets, and will give manufacturers an opportunity to see, in a simple form, what is being offered. Status: same as H. R. 3756.

**Prolific Patent Legislation**—These three bills, although important, represent a mere drop in the overflow of Congressional patent activity. Following is a survey of additional patent legislation now pending in Congress:

H. R. 5223 (Rep. Boykin), known as the "priority bill", extends the time, temporarily, for filing applications for patents. This bill was designed to meet special conditions caused by the war. It extends the application time on inventions completed since September, 1939—the theory being that the war prevented exploitation and marketing of these inventions, thus cutting into the normal 17-year life of a patent. This bill has been passed by the House and is awaiting action by the Senate Committee on Patents.

H. R. 1439 (Rep. Lanham) would prohibit an inventor from giving proofs of "acts" done by him in foreign countries. The provisions of this bill are also included as Section 9 of H. R. 5223. Status: same as H. R. 5223.

H. R. 5940 (Rep. Lanham) makes government-owned patents freely available for use by U. S. citizens. It is now being considered by the House Patent Committee.

H. R. 6071 (Rep. Beall), H. R. 718 (Rep. Elston), H. R. 1190 (Rep. O'Hara), H. R. 2043 (Rep. Rowan), H. R. 3069 (Rep. Grant of Indiana) and S. 840 (Sen. Capehart), all provide for the extension of patents for loss during war and for loss caused by military service. The House bills are before the House Committee on Patents, and the Senate bill is being considered by the corresponding Senate group.

H. R. 5311 (Rep. Henry) provides that damages in patent suits be ascertained on the basis of compensation for infringement. This bill has been passed by the House and is before the Senate Patents Committee.

Several bills which have been introduced into the House have as yet not proceeded any further than the House Committee on Patents. These are: H. R. 5506 prohibiting the sale of government patents as surplus property; H. R. 5887 (Rep. Lanham), authorizing the patenting of woven textile fabric designs; H. R. 1178 (Rep. Lanham), removing prior foreign patenting as a bar to a U. S. patent, unless such foreign patenting occurred more than 12 months prior to the U. S. application.

There are several more important bills, which are in the same predicament as the above-mentioned legislation. One, H. R. 2631 (Rep. Boykin), which would limit the life of a patent to a term commencing with the date of application (so-called "20 year bill"), had hearings from May 29 to June 7, 1945, but no action has been taken. Another, H. R. 2612 (Rep. Bailey), the "anti-cartel" bill, declares certain contracts involving patents and containing certain restrictions, to be illegal, and the patents involved null and void. Still another bill hung up in the House Committee on Patents is H. R. 3694 (Rep. Hartley) which would declare a national policy setting up a test for determining invention.

Among bills concerning patents, which have been referred to committees other than those on patents, are: H. R. 1583 (Rep. Wadsworth) which relates to patent infringement suits in the Court of Claims—House Judiciary Committee, no action; H. R. 2261 (Rep. Wadsworth), which prevents an applicant from losing his rights by failure to file suit in the proper court—same status as H. R. 1583.

Hearings on another patent bill, H. R.

*Washington Evening Star*

**An aisle in the Patent Office search room is crowded with bookcases and desks, leaving little space for those who must consult Patent Office records.**

3462 (Rep. Voorhis), which were held before the House Judiciary Committee in February, 1945, were never reported on or completed. This important bill covers three phases of patent law: (1) Intervention by the Attorney-General in patent infringement suits; (2) recording of patent agreements with the Department of Justice; (3) declaring certain uses of patents illegal, with criminal penalties and revocation of patents. No action has been taken on this measure in more than a year.

With Congress seemingly in a hurry to get started on its six-month vacation, we will not in all probability, see final action on any of the aforementioned bills until 1947.

**Lest We Forget**—The Kilgore and Fulbright bills for government support of scientific and engineering research, although supposedly offered for lofty purposes, came down to earth far enough to consider patents. For a full discussion of this aspect of science legislation, see the May "Washington Notes" columns. Persons interested in the future of our patent system should study these bills (Kilgore, S. 1850 and Fulbright, S. 1248). In the opinion of many, there is more significant patent legislation embodied in these two bills, than in all other legislation offered thus far.

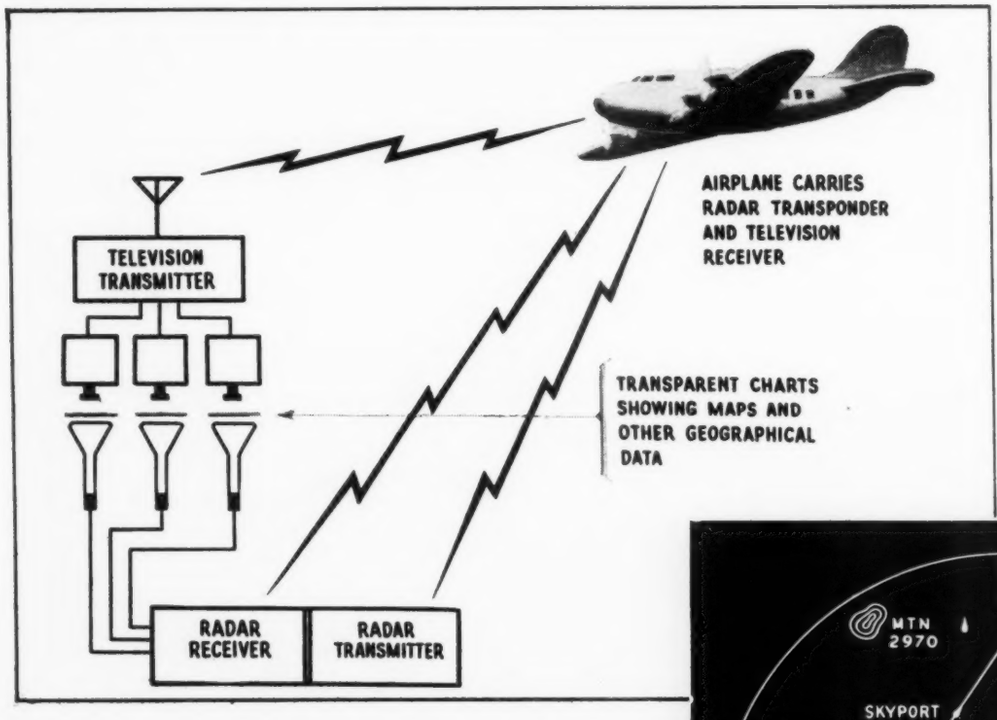
Both the Kilgore and Fulbright bills are on the Senatorial calendar, but debate may not be held before Congress recesses.

**Atomic Energy**—Senator McMahon's atomic energy bill, S. 1717, reported favorably by the Special Senate Atomic Energy Committee with the teeth pulled out of "military liaision," has significant patent features. Briefly, these are:

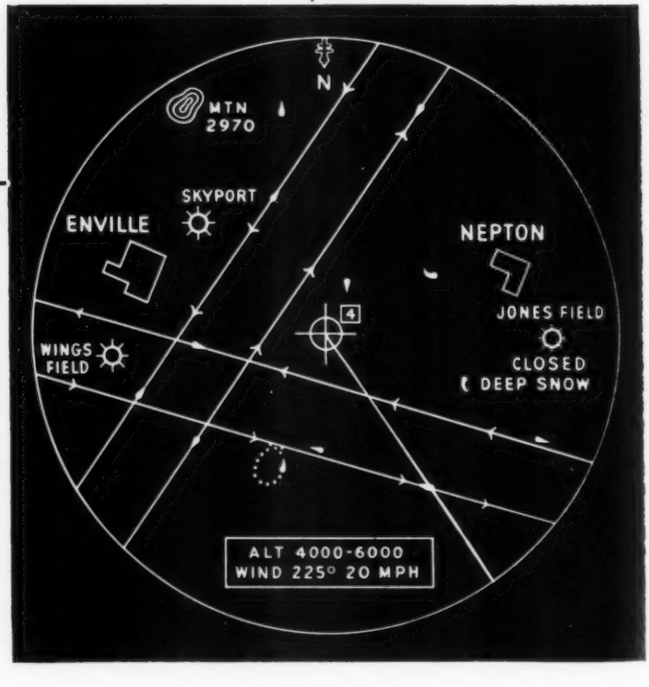
1. All private patent rights on processes for the production of fissionable materials must be sold to the government. Private production in minor quantities, for research purposes, are subject to frequent inspection and reports.

2. Private patents on devices utilizing fissionable materials are permitted, subject to compulsory licensing at "reasonable" royalty rates determined by the control Commission set up by the bill. This use is not permitted, however, until Congress has reviewed the specific conditions of use. Use of private patents is permitted 90 days after application, if Congress fails to act.

## Television-Radar Air Navigation


AIRPLANE CARRIES RADAR TRANSPONDER AND TELEVISION RECEIVER
TELEVISION TRANSMITTER
TRANSPARENT CHARTS SHOWING MAPS AND OTHER GEOGRAPHICAL DATA
RADAR RECEIVER
RADAR TRANSMITTER

**As shown in the Teleran scope (lower right diagram), the pilot's plane is identified by the radial line passing through the proper pip. Each aircraft carries a "transponder," which consists of a receiver and transmitter connected together. When this transmitter emits pulses which depend on altitude, a discriminator on the ground sorts out these responses. Geographical data are displayed on the superposed map. Altitude, wind direction and velocity are given in a box near the bottom of the Teleran picture.**




DESIGNED TO MAKE LANDING FIELD APPROACH safe and efficient, a new system of television-radar air navigation has been proposed by the Radio Corporation of America. Combining the advantages of both television and radar, the system, called Teleran, is only in the development stage, and will be ready for flight demonstrations in about 18 months.

In its simplest form, Teleran employs a ground search radar which surveys the air-space of interest and displays the information obtained on a cathode ray tube. This is viewed by a television camera, a map of the area is superposed, and the combination picture is broadcast by a television transmitter. The picture is reproduced by a television receiver in the airplane, and the pilot sees his plane as a spot of light moving across a map; other planes appear as different "pips" of light, each moving on its actual course.

Since the received picture might be confusing if all radar echoes were displayed in all aircraft and since the pilot is primarily interested in those aircraft at approximately his own altitude, the Teleram system includes a method of transmitting a separate picture for each altitude level.

# RESEARCH NOTES

## Pacific Research Foundation

The Pacific Research Foundation was organized in May, 1946 by a group of industrialists who recognized the need for a non-profit scientific and industrial research laboratory on the West Coast to serve rapidly expanding industries of the eleven western states. The industries of the East have had such a service at the Mellon Foundation at Pittsburgh. The Battelle Institute at Columbus, and the Armour Foundation at Chicago since 1911, yet on the Pacific Coast such institutions do not exist.

The Foundation will provide an outstanding staff of scientists and technicians with the most modern scientific equipment in the fields of Chemistry, Physics, Metallurgy, Mechanics and Hydraulics, Electronics, Ceramics and Bacteriology. Companies using the Foundation services will pay for the time of the scientists and engineers assigned to the project, and out-of-pocket expense for material and services.

The Foundation is under the direction of its vice president and general manager, Ernest L. Black. As a result of Mr. Black's discussions with leading scientists, complete plans for the Foundations were presented to a group of Los Angeles industrial leaders on November 11, 1945. It was the unanimous opinion of this group that such an organization was badly needed on the West Coast and recommended that a nationally prominent industrial research authority be invited to come to California and appraise the work that had been done.

Dr. Henry T. Heald, President of Illinois Institute of Technology and the Armour Research Foundation, was selected to make this appraisal. He completed his tour of the Los Angeles and San Francisco areas on January 25, 1945. He visited all the major universities and many of the industrial plants of the two areas and presented his recommendations to a group of top industrialists in San Francisco on January 26.

Dr. Heald stated "The need for a first class research organization to serve Pacific Coast industry seems to be well established. The rapid growth of industrial development to its present volume plus the prospect of a continued increase creates a substantial demand for such services. Such an organization can be of real value in assisting in the industrial development of the area. The Foundation can expect to undertake projects sponsored by (1) individual companies for the solution of specific company problems, (2) groups of companies acting through associations which are interested in problems of common interest. (3) Federal governmental agencies such as the Army and Navy, and (4) State and local governmental agencies interested in work of public or regional character."

It was Dr. Heald's opinion that operations could be started almost immediately if the facilities of Stanford University were utilized. He recommended that this group ask Stanford to cooperate with the Pacific Research Foundation by allocating the use of some of its engineering buildings and equipment. This was done at the next regular meeting of the Stanford Board of Regents on February 21. The Regents accepted the responsibility of establishing the Foundation at Stanford.

Dr. Heald also recommended that (1) the Foundation be organized as a separate corporation with trustees from both industry and from the Stanford Board of Regents (2) that it would be desirable for the Foundation to have an advisory committee including representatives of other universities as well as industrial organizations and (3) that since the Pacific Research Foundation has done an effective job of creating interest in the area, it would be desirable if the Foundation at Stanford be established in such a manner as to make it clear to industry and the public that it is the same program which has been advanced by the Pacific Research Foundation.

Dr. Clyde Williams, Director of Battelle Memorial Institute, came to California on May 23, at the invitation of Stanford University to discuss the best plan of operation for the Pacific Research Foundation.

Efforts are now being made to select the director of the Foundation. Neither the staff nor the plan of operation will be determined until he takes over his duties.

A NEW FATIGUE TESTING MACHINE, which has greater power than any other such machine in the country, was completed recently at the Technological Institute of Northwestern University. The 30-ton steel giant tests the strength of structural materials under continued and repeated stresses. It can stretch and compress a specimen 200 times a minute with both an extending and compressing force of a quarter of a million pounds.

The machine, which is 25 feet long and nine feet high and can test two separate specimens simultaneously, was designed and built by Professor Lawrence T. Wyly of the civil engineering department at Northwestern. It will be used immediately in an investigation of the strength of riveted and bolted connections, sponsored by 15 companies, engineering societies, and government agencies. The rivet research is being carried on largely at Northwestern University, under direction of Prof. George A. Maney, chairman of the civil engineering department, and at the University of Illinois, under direction of Prof. W. M. Wilson.

## Peacetime Research Grants

Scientists who have been doing war research will have the chance to get back promptly to peacetime research and teaching in colleges and universities through $2,500,000 in grants offered by the non-profit Research Corporation of New York, which develops inventions assigned to it by public-spirited inventors.

The five-year program, announced by Dr. Joseph W. Barker, acting president, will result in 100 to 200 grants of $2,500 to $5,000 each year in order that talented young scientists, engaged for the most part in war research in uniform or as civilians, will be able to undertake at universities and

colleges peacetime research in chemistry, physics, mathematics and engineering.

The grants will be made by a special committee of eminent scientists from industrial and university laboratories. The committee is composed of Acting President Barker who is also Dean of Engineering at Columbia University; Dr. Thomas H. Chilton, director of engineering for duPont; Dr. William D. Coolidge, X-ray consultant for General Electric Co.; Timothy E. Shea, manufacturing engineer of Western Electric Co.; Dr. Lloyd P. Smith, associate research director of Radio Corporation of America; Col. Stafford L. Warren, professor of medicine at the University of Rochester; and Dr. Robert R. Williams, coordinator of research of the Research Corporation.

Awards will be based primarily upon the demonstrated ability of the men who will conduct the researches and contribute to the teaching program of the school.

## Production Research

A manufacturing research center devoted to improving production methods as distinct from conventional research projects in product betterment, was announced recently by International Harvester Co.

The unit will be set up on Chicago's southwest side in a 230,000-sq. ft. surplus war plant for which Harvester is paying $1,353,000. The building formerly was used by Foote Bros. Gear & Machine Corp. in making aircraft engine parts.

The center's two basic functions will be: (1) to try out new machines and processes, whether offered by the Harvester organization or outside suppliers; (2) to find better methods for special production problems, either on request from manufacturing divisions or on the initiative of the center's own research staff.

Eight laboratories will handle plant process problems, while a methods improvement section, comprising engineers and technicians, will have the down-to-earth task of applying the center's developments in the cold light of the dollar sign. This section will be responsible for: (1) estimating the costs of changes fostered by the center; (2) recommending the sequence of production operations for new products; and (3) applying the laboratories' findings to existing manufacturing processes.

## Flying Wing Makes Its Debut

A GIANT FLYING WING, with an overload gross weight of more than 104 tons, has been completed at Northrop Aircraft, in Hawthorne, California. The Army, which designates the plane as the XB-35 bomber permitted disclosure of the following details:

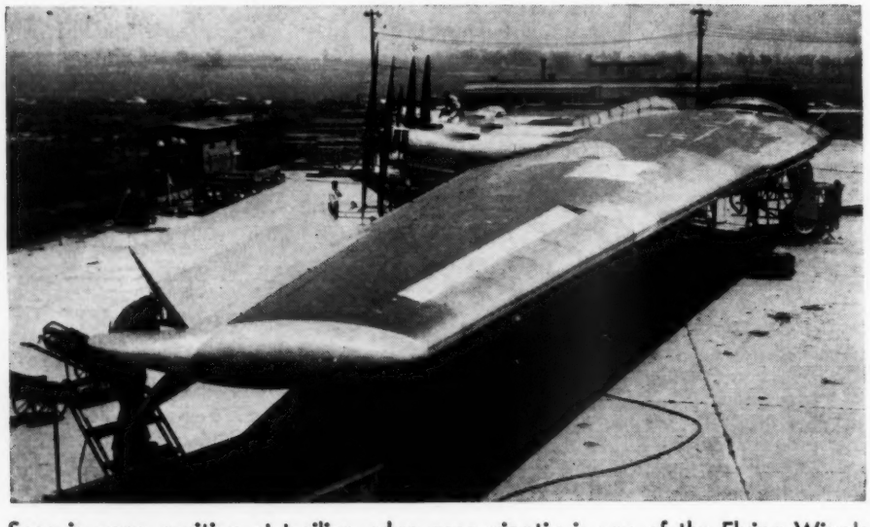
The Northrop Flying Wing is 172 feet in span, with an area of 4,000 square feet, and is capable of operating under overloading conditions at a gross weight of 209,000 pounds, more than 104 tons. It is powered with four Pratt and Whitney Wasp Major engines, turning four, eight-bladed Hamilton Standard co-axial pusher propellers, and designed to deliver a total of 12,000 horsepower under military power. The crew nacelle is pressurized.

The Flying Wing, as its name implies, has no conventional fuselage or tail surfaces. It is shaped like a giant boomerang and carries its engines in submerged housings which do not protrude from the wing surface.

Control is achieved by means of "elevons," a Northrop development combining the functions of both elevators and ailerons. Normal crew for the XB-35, is nine men: pilot, co-pilot, bombardier, navigator, engineer, radio operator and three gunners.

Size of the XB-35 may be estimated from the fact that these 15 men are housed entirely within the wing itself. The only protuberances necessary are added to house the defensive armament.

The XB-35's overload gross weight of 209,000 pounds (104½ tons) compares with a weight of 130,000 pounds (65 tons) for the B-29, the Army's heavyweight bomber of World War II.



**Seen in open position at trailing edge near wingtip is one of the Flying Wing's novel clam-shell type drag rudders. Swept-back wing is adaptable to sonic speeds.**

The Northrop Flying Wing XB-35 is built with a new aluminum alloy developed by Alcoa which, tests have shown, is considerably stronger than previous materials of similar nature. The XB-35 carries gasoline in bulletproof, leakproof tanks, and can carry additional gallons in tanks in its bomb bays and other wing compartments.

The wing section itself is 37½ feet long at the center, tapering to slightly more than nine feet at its tips. It sweeps back from center to tips, making the overall length of the ship slightly more than 53 feet. It stands over 20 feet high when at rest on its tricycle landing gear, which is equipped with five-foot six-inch dual wheels on the main gear, and a four-foot eight-inch wheel on the nose gear. The plane is expected to weigh 89,000 pounds. It is shown above in an artist's sketch. This is the first of 15 such planes to be made by Northrop under Army contract.

## RECENTLY ELECTED SOCIETY OFFICERS

**Pressed Metal Institute,** 829 Union Commerce Bldg., Cleveland, Ohio. President—Clarence W. Custer, American Stamping Co.; Vice President—Carter C. Higgins, Worcester Pressed Steel Co.; Secretary-Treasurer—J. J. Boelim, Boelim Pressed Steel Co.

**Society of Naval Architects and Marine Engineers,** 29 W. 39th St., New York 18, N. Y. President—William S. Newell, Bath Iron Works; Secretary Treasurer—J. H. King, Babcock and Wilcox Co.; Assistant Secretary—Arlo Wilson.

**American Society of Tool Engineers,** 1666 Penobscot Bldg., Detroit, Mich. President—A. M. Sargent, Pioneer Engineering and Mfg. Company; Vice President—W. B. Peirce, Flannery Bolt Co.; Secretary—R. B. Douglas, Canadian Car and Foundry Co.

## MEETINGS

**Society for Experimental Stress Analysis**—Spring meeting, including symposium on fatigue of manufactured parts, held jointly with A.S.T.M., June 24-26, Hotel Statler, Buffalo, N. Y.

**American Electroplaters' Society**—National meeting, June 17-20, William Penn Hotel, Pittsburgh, Pa.

**American Institute of Electrical Engineers**—Summer Convention, June 24-28, Hotel Statler, Detroit.

**American Society of Mechanical Engineers**—Semi-annual meeting, including first technical session of the Machine Design group, June 17-20, Hotel Statler, Detroit. Aviation Division meeting, June 3-6, University of California, Los Angeles. Power Division meeting, June 12-15, Hotel Schroeder, Milwaukee. Applied Mechanics Division meeting, June 21-22, Hotel Shaerton, Buffalo.

**National Association of Power Engineers**—Annual convention and Power Show, August 19-23, Hotel Cleveland, Cleveland, Ohio.

**Metal Powder Association**—Spring meeting, June 13, Waldorf-Astoria Hotel, New York.

**American Society for Testing Materials**—Annual meeting, June 24-28, Hotel Statler, Buffalo, N. Y.

**Institute of Areonautical Sciences**—Summer meeting, July 18-19, Hotel Hollywood-Roosevelt, Los Angeles, California. Light Aircraft Meeting, June 13-14, Horace H. Rockham Educational Memorial, Detroit, Mich.

**American Mathematical Society**—Summer meeting and Colloquium, Aug. 20-23, Cornell University, Ithaca, N. Y.

**Highlight of the meeting of the Society of the Plastics Industry, held concurrently with the Plastics Show. Dr. E. R. Weidlein, Director of the Mellon Institute of Industrial Research presents the John Wesley Hyatt Award to Virgil E. Meharg, Bakelite Corporation, and Paul D. Zottu, Consulting Engineer, for their contribution to the plastics industry by developing high frequency heating for plastics.**

## First Plastics Exposition Attracts Wide Interest

HELD IN CONJUNCTION with the annual meeting of the Society of the Plastics Industry, the huge plastics show arranged by S.P.I. brought peacetime plastics home to thousands of businessmen and plain citizens at New York's Grand Central Palace. Freed from the restrictions of war production, the plastics industry put itself on display for the benefit of about a third of a million buyers, manufacturers and engineers, and about an equal number of the general public.

Nearly 200 exhibitors at the show offered a brief education in the production, molding, fabricating and finishing of plastic materials and products. With this profusion of products and processes, we can present only a few highlights here:

A thermoplastic sheet material which can be deep drawn was announced by the Hercules Powder Company. Laminated with cellulose plastics, the sheets can be produced in any color. Limited commercial quantities of this material are being made by Hercules in 48x48 inch flat sheets. Heat-forming and deep drawing can be achieved with low-pressure equipment.

A low-cost injection syringe, was exhibited by the Celanese Plastics Corporation. Injection molded of cellulose acetate, the syringe is used for one-time injection of penicillin. This is made possible by the low cost of the syringe.

Silicone rubber was featured at the General Electric exhibit. This material is especially suitable for high-temperature insulation applications. During the war it was used extensively in searchlights and superchargers.

Electronic heat sealing was shown at the exhibit of the Radio Corporation of America. Used in the fabrication of clothing and packaging from thermoplastic sheet materials, this method has several advantages. High-frequency electrical energy is converted into heat only within the material, the electrodes remaining cool. This results in getting heat where it is wanted.

An organic high-temperature baking enamel, called POL, was demonstrated by the Naugatuck Chemical Division of the United States Rubber Company. These enamels, although somewhat higher-priced than ordinary resin finishes, are claimed to be superior in long life, resistance to high temperatures and resistance to acids and alkalis.

Cellular cellulose acetate and a new resin, Teflon, were outstanding at the DuPont Company's exhibit. CCA, DuPont's trade name for cellular cellulose acetate, is an oriented, multicellular form of cellulose acetate, whose primary use is as a core material in sandwich laminates. Its function is to increase stiffness without increasing weight. The product is available in the form of extruded boards. Teflon, the wax-like plastic which resists attack by the strongest acids, was described in "Industry and Societies" for May. Its principal use will be for gaskets, seals and insulation. "BCM", a new thermosetting liquid resin which requires low pressures and short curing time, was shown as a binder for glass fabric

laminates. Another new product shown by DuPont was solid nylon sheeting, which is expected to have leather-like applications.

New forms of standard plastics were evident at the show. Dow exhibited silicones as resins, low and high temperature lubricants, high temperature electrical insulation, and in paints. B. F. Goodrich exhibited allyl cast resins, trade-named Kriston, in gem-like colors for potential application in the electrical, optical and laminating fields. This company also showed polyvinyl chloride in electrical insulation and moisture-resistant applications. The American Cynamid exhibit featured electrical parts molded from melamine-formaldehyde resins.

Of great interest was the molding and hobbing equipment exhibited. Included were a two million pound hobbing press with bullet-proof windows, shown by the Elmes Engineering Works; an injection molding machine which featured easy access to the nozzle, shown by the Leominster Tool Company; and a large 12-ounce injection press, shown by the Watson-Stillman Co.

Discussing the materials supply situation at one of the S.P.I. technical meetings held concurrently with the Plastics Show, W. Stuart Landes, President of the Plastics Materials Manufacturers Association, disclosed that the tremendous growth of the plastics fabricating industry has resulted in an alarming shortage of molding materials.

## Lists of Seized Enemy Patents To Be Distributed

THE OFFICE OF ALIEN PROPERTY CUSTODIAN, in response to wide demand, has compiled lists of United States patents seized from enemy aliens on nearly 100 different subjects of popular interest. Most of these patents are available for licensing to American citizens on a non-exclusive royalty-free basis for the remaining life of the patents. A fee of $15 is charged for each patent.

A list of the subjects covered by these patents, together with an Index and Guide to the vested patents may be obtained free of charge from any of the Alien Property Custodian libraries listed below. There are maintained at each of these libraries complete files of copies of vested patents, abstracts of these patents, as well as the Register of Patents Available for Licensing or Sale, published by the United States Patent Office:

Washington 25, D. C. National Press Bldg., 14th and F Streets.

Chicago 3, Illinois. Field Building, 135 South La Salle Street.

New York 5, N. Y. 120 Broadway.

Boston 8, Massachusetts. 1 Court Street.

Los Angeles 13, California. 530 South Hope Street.

Kansas City, Missouri. Midwest Research Institute, 4049 Pennsylvania.

# DISCUSSIONS AND COMMENTS FROM READERS

## "The Suppression of Patents"

*To the Editor:*

Alexander Morrow, the author of "The Suppression of Patents", abstracted in the February issue of Product Engineering, contends that "numerous practices, resulting in the withholding of the patents from the public, have become encrusted in our patent system". Mr. Morrow's conclusions appear to be based on incomplete or unverified information. For instance, Mr. Morrow cites an engineer as saying that a large electrical manufacturing company had a great deal of money, equipment and stock invested in sleeve-bearing motors and that they had no intention of putting out ball-bearing motors for some years.

Whether a sleeve-bearing motor or ball-bearing motor was to be used by a customer obviously depended upon the customer's needs. In the motor sizes where a difference in friction losses between a sleeve-bearing motor and ball-bearing motor were a relatively small percentage of the total motor output in comparison with the additional cost to the customer of a ball-bearing motor, the customer would have been ill-advised to insist on having a ball-bearing motor. It is relatively seldom that any customer is willing to pay the price in money, time-delay, and other deterring factors such as additional care, for example, to obtain the highest available theoretical mechanical efficiency of the equipment.

The fact that sleeve-bearing motors were still sold when ball-bearing motors were available does not appear to be any evidence in support of an assertion that there was any suppression of patents.

The very persons who criticize the sale of sleeve-bearing motors are apt to be the ones who accused manufacturers of deliberately making lamps that burn out in 1,000 hours instead of 2,000 hours notwithstanding that in so doing luminous efficiency can be greatly raised and overall cost of electric current plus purchase price of lamps be considerably reduced.

Mr. Morrow also refers, on pages 212 and 213 of his article, to the fact that foreign countries have provisions in their laws for compulsory licensing or working without showing that any benefit whatsoever has resulted from such provisions in the laws of foreign countries. It is understood that the provision for compulsory licenses in Great Britain is invoked in connection with less than 1 percent of all the British patents. Compulsory license provisions have not been considered satisfactory by Englishmen.

It is well known that most foreign countires are backward with regard to mechanical and industrial improvements. The fact that one's competitor can obtain a compulsory license on an improved, or what Morrow calls, "an alternative" method or machine can hardly be regarded as any inducement for engaging in development and research. Under such a practice it is much easier and there is a natural tendency to sit back and wait for the competitors to make improvements and devise "alternatives" and then copy the successful developments subject to royalty payment while rejecting the unsuccessful ones without having incurred any development expense.

—FREDERIC B. SCHRAMM
*Richey & Watts*

*To the Editor:*

The article entitled "Suppression of Patents" by Mr. Alexander Morrow assumes the fact of patent suppression, without citing a single patent which has been suppressed, and then attempts to state the motives for suppression.

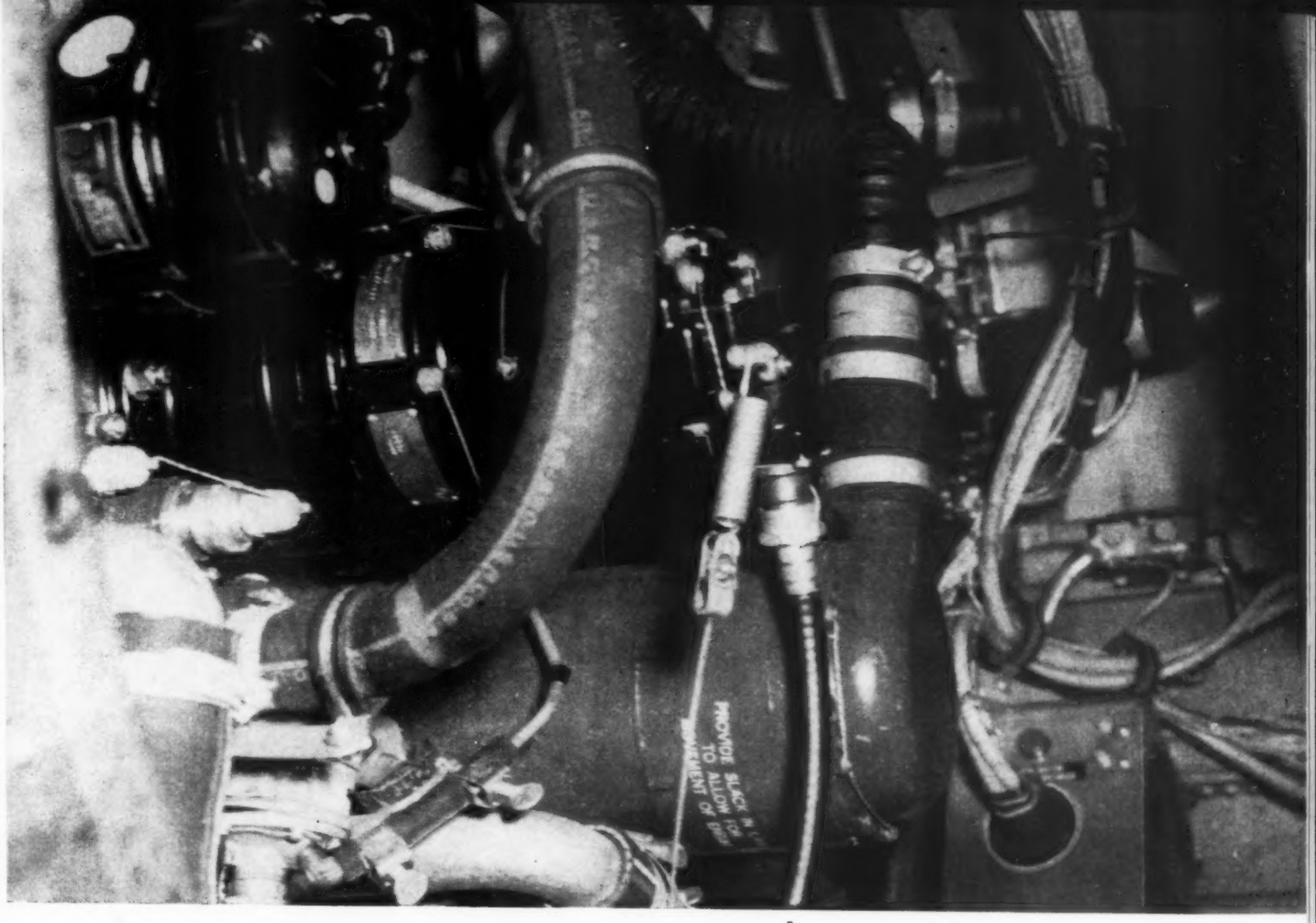
The nonuse of patents is not suppression any more than the failure to cultivate non-profitable acres, or the refusal of a housewife to substitute the discarded coal range in her basement for her modern electric cooking stove, is suppression. Progress and profit necessitate the use by manufacturers of the best of alternative articles, devices and processes.

The most fundamental error of the article, however, is its failure to appreciate the fact that the main purpose of the patent laws as stated in the Constitution itself is to promote the progress of the sciences and useful arts by the mere grant of patents for what was theretofore unknown, irrespective of the use the patent owner makes of them. In this way the sum total of scientific knowledge is and has been constantly increased. Such knowledge constitutes the basis for additional new inventions. Illustrations could be cited by the thousands. One example is the synthetic rubber patents, such as patents Nos. 1,938,730 and 1,938,731, disclosing that kind of expensive synthetic rubber now used for automobile tires, which, according to Mr. Morrow's theory, were "suppressed" from the date of the grants of such patents in 1933 until our source of supply of cheap natural rubber was cut off by the Japanese at the outbreak of the war. Lack of supply of natural rubber compelled their use during the war regardless of the expense involved.

Another example is the crystal radio set powered by storage batteries. Many of the patents pertaining to these sets are "suppressed", that is, not used by the owners. However, they are undoubtedly available for use by anyone who wants to use them.

With a little investigation Mr. Morrow could have learned that his premise is unsound. Extensive hearings before committees of Congress failed to reveal a single instance of patent suppression. (See T.N.E.C. Hearings, 75 Cong., 1939 part 3; Hearings before a Subcommittee of the House Committee on Patents, 75th Cong., 3d Sess., pursuant to H.R. 9529, H.R. 9815 and H.R. 1666, and Oldfield Revision and Codification of Patent Laws, 1914, 63d. Cong., 2d session.

—CONDER C. HENRY
*Assistant Commissioner*
*U. S. Patent Office*



# Alternating Current Power For Large Aircraft

**T. B. HOLLIDAY***
President, Mueller Accessories, Inc.

**Analysis and interpretation of the complex engineering considerations that resulted in adoption of 400 cycle a.c. power for large aircraft. Relative advantages of a.c. and d.c. power, methods of distribution, voltage and frequency combinations, and constant speed differential couplings are discussed.**

THE ADVENT of large electrical systems for the super air-transports raises the question of whether direct current or alternating current power is better suited to the needs of aircraft.

The advantages of direct current power are: (1) generators can operate at variable speed, (2) generators can be paralleled by adjustment of voltage only, (3) d. c. motors have desirable torque characteristics.

The advantages of alternating current are: (1) the transformer is a compact and efficient means for changing voltage, (2) the induction motor is the simplest rotary electrical device.

Principal limitations include the necessity for commutators in direct current machines and the existence of power factor in alternating current systems.

The single purpose of improvements in the electrical system for aircraft is to reduce weight. Weight is the primary consideration for the design engineer, because reduction in weight permits a corresponding increase in pay load and pay load determines the revenue returned by the airplane. It has been often proved that a pound saved in airplane equipment is worth its weight in gold.

The weight of most components in the electrical system are directly proportional to

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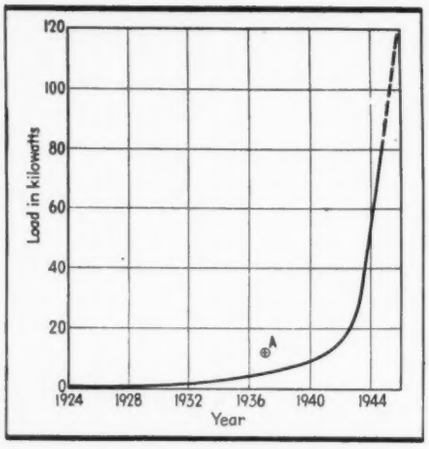



**Fig. 1—Growth of installed generator capacity and connected load in military aircraft for the past twenty-one years.**

power, and only slightly affected by voltage. However, the weight of the wiring is directly affected by the voltage. Increase in voltage decreases the wiring weight out of all proportion to the increase in voltage. In one instance a change in voltage from 30 volts d.c. to 200 volts a.c. saved approximately one ton of wire. The larger that airplanes become, the greater is the relative saving.

As the size of airplanes has increased the connected electrical load has increased, as shown in Fig. 1. The growth curve rises as an exponential law because of the increase in size of the aircraft and the concurrent increase of electrical power for accessory uses. As shown on the curve, point A in 1937 marks the beginning of the use of auxiliary power units for aircraft, when the XB-15 carried a 110 volt 800-cycle generator for supplying auxiliaries.

The distribution of weight in three types of airplanes is shown by Fig. 2. It is significant that the weight of wiring for the 30 volt systems used by all three planes increases faster than the weight of the airplane. Although it is only 29 percent of the total electrical system weight in a two-engine airplane, it is 35 percent of that in a large four-engine airplane. Also the bar charts reveal that although airplane C is only about three times larger than airplane A, the weight of the electric wiring is more than six times that of A. The values shown in Fig. 2 and in Tables I, II and III may not agree with the exact weight report for any individual airplane because of company differences in segregation and allocation of various components. However, they do give the general pattern of distribution of weight.

The theoretical benefits that result from increasing the voltage is shown by Fig. 3. If the voltage is quadrupled, theoretically, for supplying the same load only one-sixteenth the weight of conductor is re-

**Table I—Comparison of Weight of Three Types and Sizes of Military Aircraft in Rounded Numbers**

| | Distribution of empty weight, lb. | | |
|---|---|---|---|
| | Plane A | Plane B | Plane C |
| Structure | 9,200 | 15,500 | 35,000 |
| Power Plant | 7,500 | 13,500 | 23,900 |
| Equipment | 5,300 | 7,000 | 11,100 |
| Total, weight empty | 22,000 | 36,000 | 70,000 |

**Table II—Estimated Distribution of Approximate Weight of Equipment of Planes A, B, C, in Table I**

| | Plane A, lb. | Plane B, lb. | Plane C, lb. |
|---|---|---|---|
| Deicing | 100 | 299 | 276 |
| Hydraulic | 144 | ... | ... |
| Furnishings | 537 | 998 | 2,293 |
| Armament | 3,025 | 2,929 | 4,702 |
| Surface controls | 305 | 572 | 727 |
| Instruments | 102 | 268 | 243 |
| Radio | 379 | 631 | 560 |
| Power | 265 | 430 | 621 |
| Wiring | 182 | 550 | 1,381 |
| Motors, starting | 111 | 204 | 209 |
| Other | 130 | 150 | 55 |
| Total | 5,280 | 7,031 | 11,067 |

**Table III—Estimated Distribution of Approximate Weight of Electrical Equipment of Planes A, B, and C, in Table I**

| | Plane A, lb. | Plane B, lb. | Plane C, lb. |
|---|---|---|---|
| Motors, starting | 111 | 204 | 209 |
| Motors, deicing | 5 | 16 | 10 |
| Motors, armament | 25 | 60 | 120 |
| Motors, furnishings | .. | 100 | 200 |
| Motors, instruments | 10 | 60 | 60 |
| Generators and controls | 96 | 193 | 263 |
| Batteries | 169 | 237 | 82 |
| Auxiliary power unit | .. | .. | 276 |
| Instruments, electrical | 4 | 4 | 5 |
| Lighting | 26 | 46 | 50 |
| Wiring | 97 | 317 | 901 |
| Conduit | 10 | 22 | 86 |
| Boxes, panels, shields | 38 | 121 | 101 |
| Relays and solenoids | 9 | 50 | 97 |
| Plugs and receptacles | 16 | .. | 138 |
| Switches and rheostats | 12 | 40 | 58 |

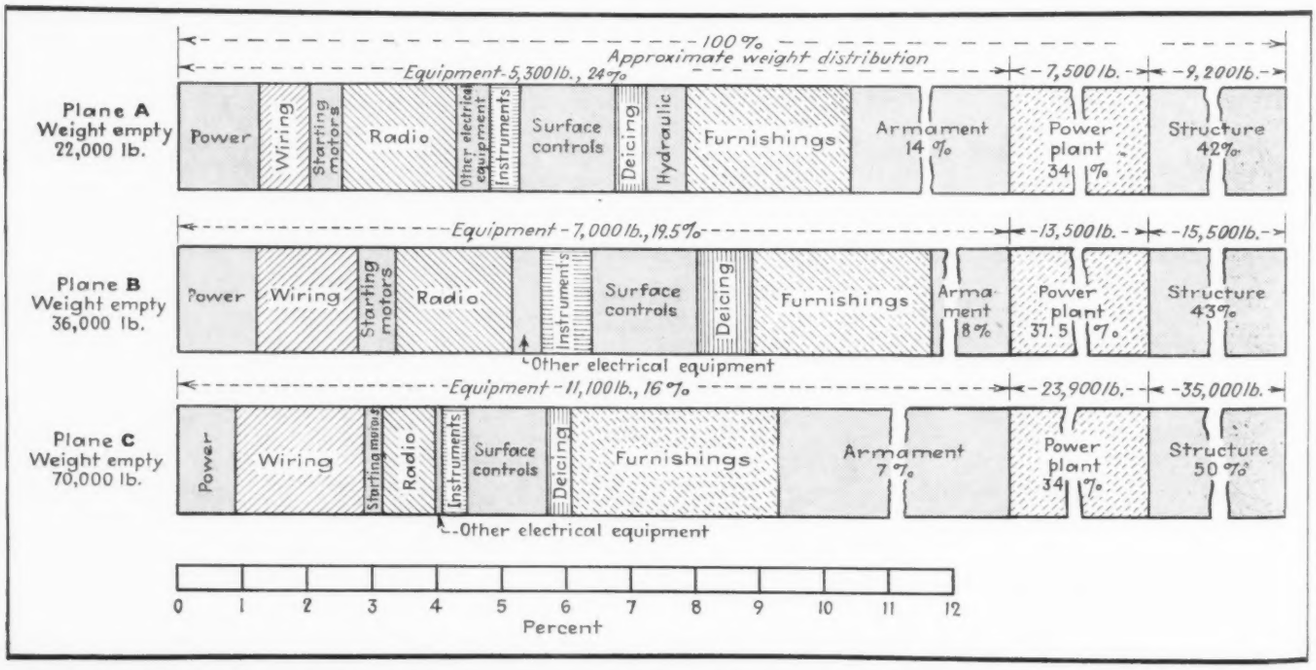



**Fig. 2—Weight distribution in three of military airplanes with empty weights of: A-22,000 lb.; B-36,000 lb.; and C-70,000 lb.**

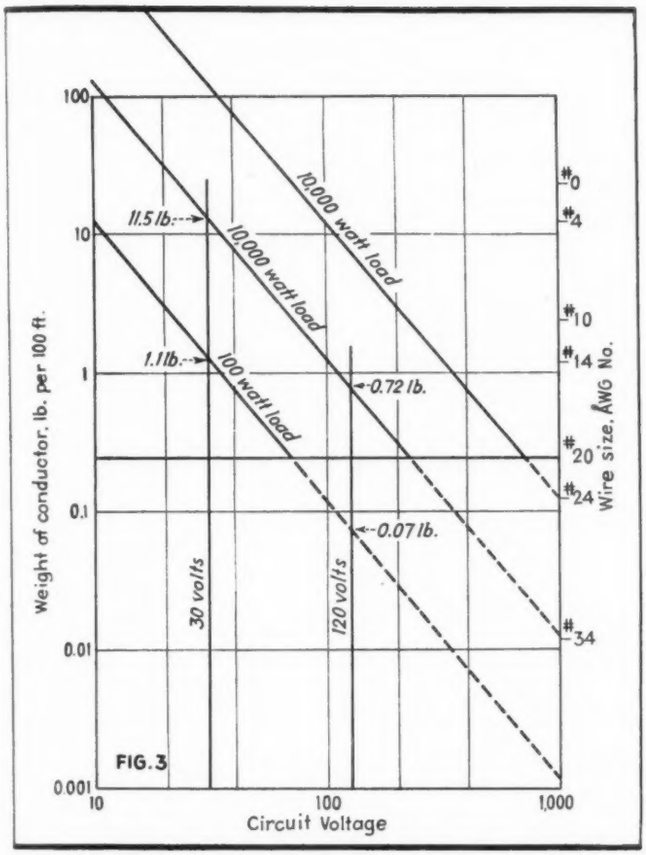



Fig 3—Graph showing the theoretical benefit of increasing the distribution voltage in terms of weight per 100 ft. of copper conductor operating at 97 percent efficiency.

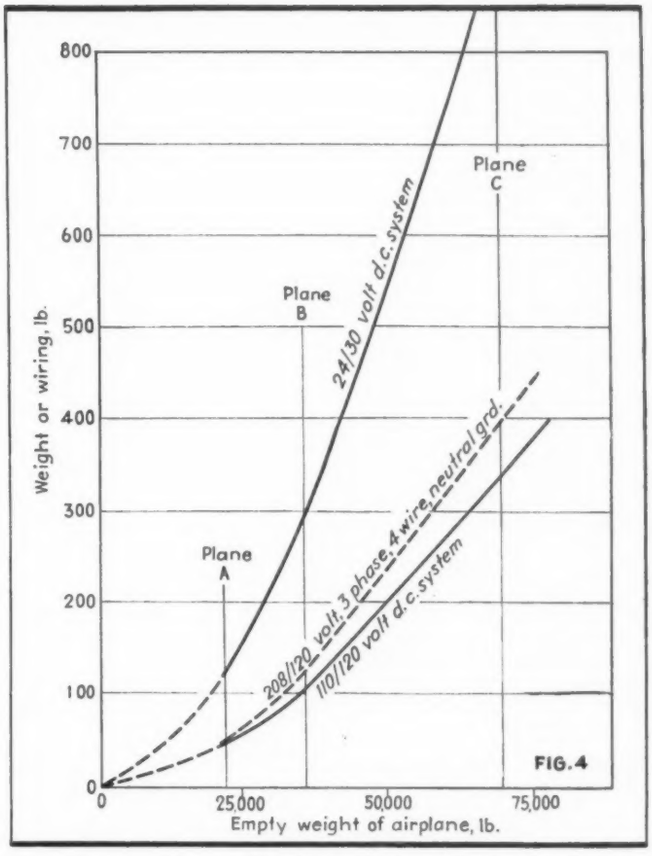



Fig. 4—Practical realtionship of the weight of wiring of different voltage systems for various weights of aircraft. The larger the airplane the greater the relative saving.

quired. For example, to supply a 100 watt load at 30 volts requires 1.12 lb. of copper per 100 ft.; but at 120 volts it requires only 0.07 lb. Similarly for 1,000 watts, 30 volts requires about 11.5 lb. of copper, but 120 volts requires only one-sixteenth of that weight.

It is not always practical to gain the theoretical saving in weight, because for mechanical reasons AWG No. 20 wire is the smallest conductor recommended for aircraft wiring. Smaller conductors can be damaged or broken during installation or while in use in the airplane. As shown by Fig. 4, using a 120 volt d.c. system instead of a 30 volt d.c. system, a 22,000 lb. plane saves about 80 lb. of copper, and a 36,000 lb. plane saves 200 lb. of copper. The size of plane increased about 60 percent but the weight of copper increased a 150 percent. The a.c. system shown requires about 10 to 20 percent more weight of wiring than the 120 volt d.c. system.

Another approach for comparing the relative merits of d.c. and a.c. is an analysis of the kind of current required for the various electrical loads in military aircraft. An airplane using a primary electrical system of direct current, must convert approximately one-fourth of the total power to alternating current power for use in radio, radar and control equipment. Conversely, if the power is a.c., only, two percent must be converted to d.c. for supplying solenoids and microphones. Approximately 75 percent of the total electrical load of the airplane, including motors, lighting equipment, and heaters, can use either a.c. or d.c., but approximately 23 percent requires alternating current power.

Another factor in the design of electrical system for aircraft is the selection of the electrical distribution system. Most aircraft have all-metal construction which serves as a return circuit for either a.c. or d.c. A related problem is the choice of the number of phases in an a.c. system. A three-phase system permits better motor design. A single-phase system is simpler and requires no balancing of loads.

If a three-phase distribution system is used it may be connected in delta or wye. If neither is grounded there is little difference. But a four-wire wye circuit with a grounded neutral has many advantages. In the four-wire system, if one line is broken the electric motor will still operate at 80 percent starting and running torque; if two lines are severed, the motors will deliver 50 percent running torque for a short time. From an analysis of these factors, the Army Air Forces selected a 208/120 volt, three-phase, four-wire system for development. This makes available three single-phase power lines with standard 120 volts from each phase to ground.

From a similar analysis, the best d.c. system is a high voltage three-wire system. In an all-metal aircraft with the mid-point of the system grounded, two 120 volt circuits to ground and a single 240 volt circuit between lines are provided.

The next problem is the choice of frequency. A direct current machine is simply an alternating current machine with a commutator; a modern direct current machine operates at relatively high internal frequency. Steady progress has been made in reducing the weight and improving the efficiency of d.c. generators and motors. Most of these machines operate at internal frequencies of 200 to 300 cycles per second, which is commutated for direct current operation. During initial studies of the alternating current system for aircraft, the frequencies that were considered included 60, 120, 180, 240, 360 and 800 cycles per second. Engineers of the Army Air Forces considered using a multiple of the industrial frequency of 60 cycles per second but discovered no particular advantages. The final choice was 400 cycles per second. As shown in Fig. 5, this was a compromise between certain advantages of 200 cycles per second and 800 cycles per second or even higher.

Another factor in the choice of frequency

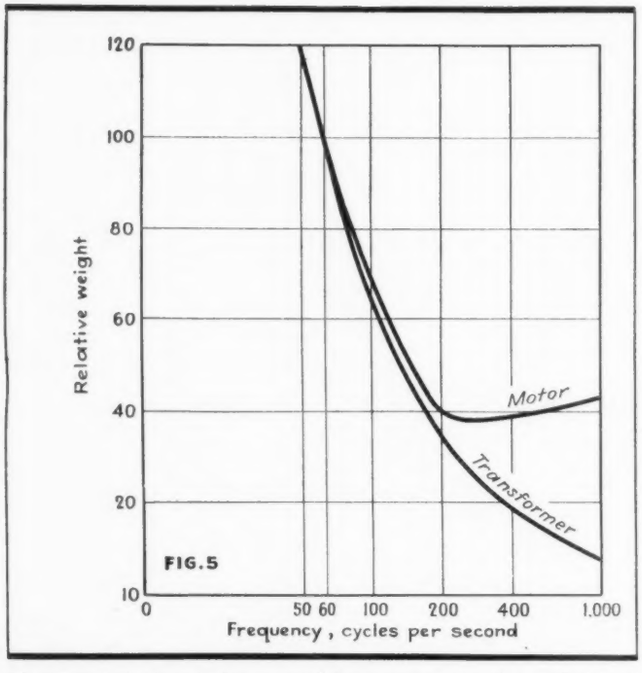



**Fig. 5—Relative influence of frequency on the weight of alternating current transformers and induction motors.**

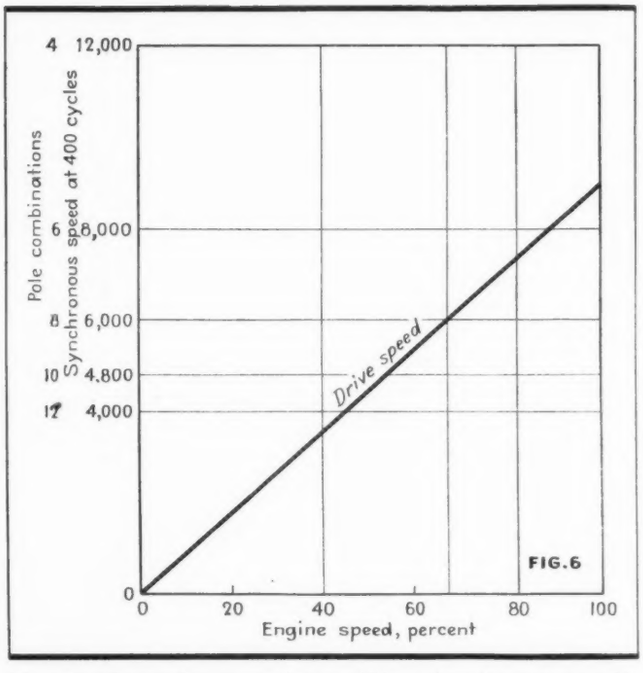



**Fig. 6—Operating speed for 400-cycle alternators with various pole combinations in relation to the drive speed.**

was the operating speed of induction motors. In Table IV are shown the synchronous speeds for 800, 400, and 200 cycles.

The practical utilization of these high speeds for motors is limited by lubrication and mechanical design problems. At present, grease lubricated ball bearings cannot be considered reliable at speeds above 12,000 r.p.m. Oil lubricated bearings have been successfully used as high as 35,000 r.p.m., but the elaborate oiling system is difficult to apply on a small motor. Therefore, the two-pole 800-cycle motor is impractical; and the four-pole 800-cycle motor and the two-pole 400-cycle motor are not reliable. As the number of poles increase the power factor of the motor decreases and this is an undesirable trait. Therefore, the final choice of 400 cycles is a reasonable compromise since there is some opportunity for improvement in motor speeds, while reliable, efficient, and quite useful speeds are available today.

The next factor to be considered in the design of a.c. systems is the relation of voltage and frequency. There are three possible combinations:

1. Variable frequency and variable voltage,
2. Variable frequency and fixed voltage,
3. Fixed frequency and fixed voltage.

Variable frequency and variable voltage, means that voltage changes in proportion to speed and frequency. This combination is satisfactory for motors only. The second combination of variable frequency and fixed voltage is satisfactory for radio, lighting and heating devices. The third combination of fixed frequency and fixed voltage is satisfactory for any type of load and the efforts have been concentrated on it.

Since it is essential that the electric generators be driven by the main airplane engines and since the electrical system cannot dictate the operating conditions for the main engines, it is necessary to drive the alternator through a constant speed coupling connected to the engine. The design of a suitable constant speed coupling has been the greatest single problem in the development of the a.c. system. The relative spread in engine speed for idling and take-off, shown in Fig. 6, is common to practically all internal combustion reciprocating engines. As the size of the engines increases, the spread in cruising speeds increases. Since the a.c. system has the greatest benefits in large aircraft it is necessary that the coupling function over a speed range of at least three to one, as shown. The constant speed coupling drives the generator at constant speed over a range from 35 to 105 percent engine speed. In other words, normal operation is from 40 to 100 percent engine speed with a 5 percent margin at the low and high speed. If it could function over a range of six to one it would be of still greater benefit, since electrical power could be delivered at engine idling speeds.

The output side of a constant speed drive must be designed for the desired alternator speed. The possible speeds for 400-cycle alternators are 24,000, 12,000, 8,000, 6,000 and 4,800 r.p.m. dependent upon the choice of poles. The alternator weight will decrease as speed is increased. For reasons of lubrication and mechanical design the 24,000 r.p.m. machine appears to be impractical at this time. Most efforts have been devoted to the 6,000 and 8,000 r.p.m. designs, even though the 12,000 r.p.m. machine should show advantage over both.

**Table IV—Motor Speeds for 800, 400, and 200 Cycles**

| Poles | R.p.m. at 800 cycles | R.p.m. at 400 cycles | R.p.m. at 200 cycles |
|---|---|---|---|
| 2 | 48,000 | 24,000 | 12,000 |
| 4 | 24,000 | 12,000 | 6,000 |
| 6 | 16,000 | 8,000 | 4,000 |
| 8 | 12,000 | 6,000 | 3,000 |

The coupling from engine to alternator in the constant frequency electrical system can be mechanical or electrical. In the mechanical type of coupling, hydraulic, mechanical, electrical, and fluid clutch designs are possibilities. A noteworthy electrical and electronic coupling uses a variable frequency alternator the output of which is rectified to d.c. and converted to constant frequency a.c. by electronic circuits. This method appears promising.

The mechanical coupling attempts to use speed and torque interchangeably in order to maintain high efficiency. Most of the hydraulic and mechanical drives that have been designed operate on a differential principle. By this method the power actually required for the drive is only the differential power, which is approximately one-third of the total rating. In hydraulic couplings this differential power is supplied by a hydraulic pump and motor. In mechanical couplings it is done with overriding clutches. Electrical equivalents of either of these use an electric motor and generator to deliver the differential power.

The use of the differential principle in a hydraulic drive is shown in Fig. 7. In this system a variable displacement pump

is used to drive a hydraulic motor and supply the difference in speed or torque as required by the alternator. As shown in Fig. 7(A), from 40 to 66 percent of engine speed, the variable element acts as a pump; at 66 percent engine speed the coupling merely "floats"; from 66 to 100 percent engine speed the variable element acts as a motor reducing the input torque. In tests, the speed regulation of the hydraulic differential couplings driving two 30 kw. alternators was so accurate that the generators divided the electrical load within about two percent. In addition, the drive was "soft" enough that synchronizing devices were not needed. It was possible to throw the second alternator on the line by simply closing the line switch. In Fig. 7(C), if the integral coupling were separated at Z it could be used as a hydraulic power coupling but would have to supply total, instead of differential, power. Although this design uses barrel pumps, any type of good hydraulic pump would do. Because the unit converts large amounts of power continuously, efficiency is more important than any other factor.

Two types of couplings which at first seem to be logical applications are the eddy current drive and fluid clutch. The objection to drives of this type is that they are not variable torque devices, and are therefore very inefficient at higher than rated speeds. Such couplings must be designed for the minimum expected operating speed of the alternator. Since this minimum speed will never be actually used, the coupling will be operated at some higher speed and the surplus power must be dissipated as waste. With a 30 kw. alternator, a 75 hp. drive is needed; and since the operating speed can easily be twice the minimum it is necessary to waste as much power as is used.

The advisability of using separate drives for alternators inevitably rises. This requires at least two auxiliary power units to drive two alternators. This auxiliary power unit can be a conventional internal combustion engine, an internal combustion turbine, or perhaps a steam turbine. However, such a power unit will be heavier than an engine driven alternator with constant speed drive and the power unit will require space within the fuselage or wing. Also, it will require as careful maintenance and impose almost as many difficulties as that required by the main engines. Finally, the fuel economy of small engines cannot compare with that of large engines.

However, future developments in small turbines may offset these disadvantages. The turbine, due to its high speed, and simple construction, should do much to eliminate the objections of weight, space, and maintenance. Also, promising developments in turbine design may result in fuel consumption which is competitive with that of larger engines.

The idea of utilizing waste heat from

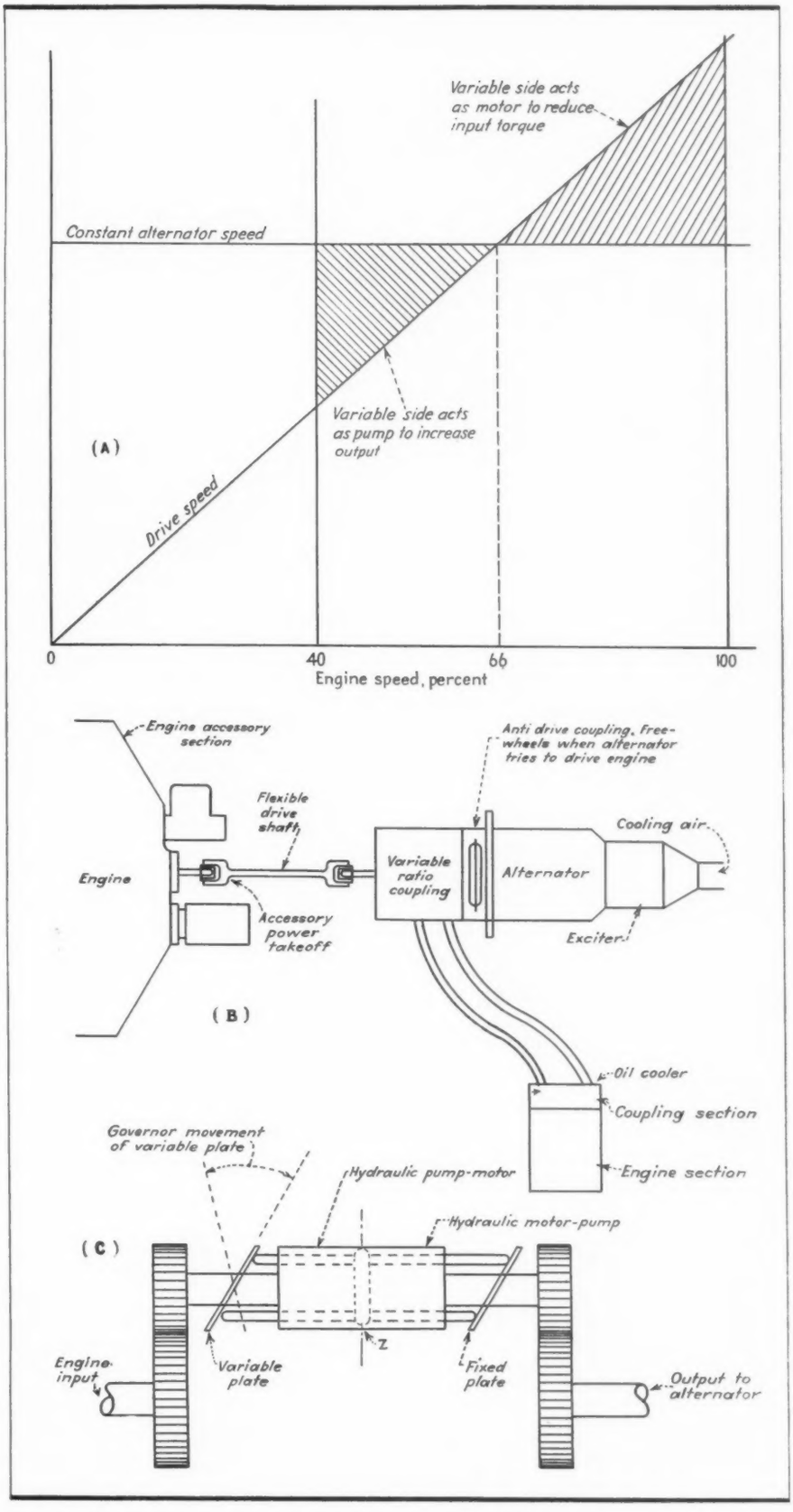



**Fig. 7—Many constant speed couplings use only differential power. (A) Typical operating chart based on 3000 r.p.m. at take off. (B) Schematic arrangement of a typical auxiliary power drive. (C) Schematic of a variable-ratio constant speed hydraulic coupling operating on only differential power.**

Fig. 8—A typical 30 kw. 400 cycle alternator weighs 75 pounds or 2.5 lb. per kw. This is about three-fifths the weight of an equivalent d.c. generator.

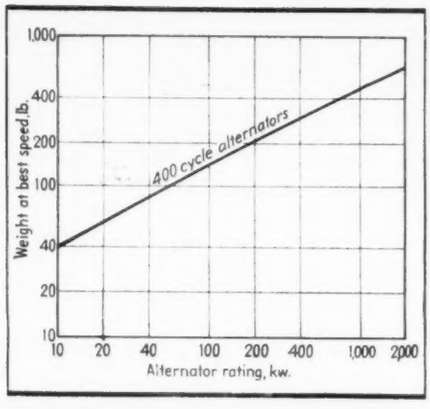
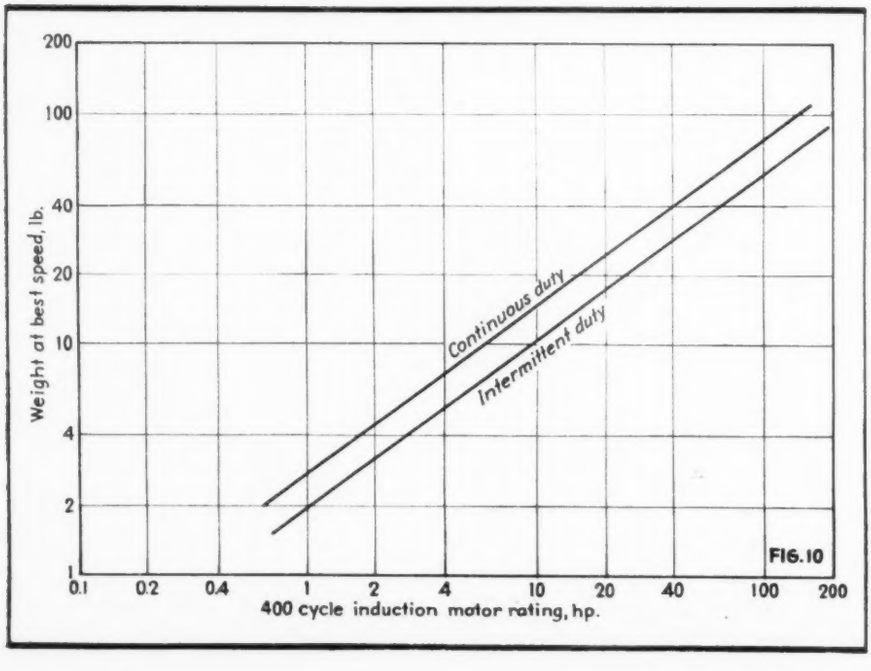



Fig. 9—Relative weight of 400-cycle alternators ranging from 10 to 2,000 kw.

Fig. 10—Relative weight of 400-cycle induction motors up to 200 hp.




the main engine exhaust system to operate boiler and turbine has been tested experimentally. This method will operate, but it is necessary to use a continuous flow or circulating water system. The design and weight of a condenser for such a system has been its greatest handicap.

Design of the a.c. aircraft system has resulted in marked reductions in weight and size of electrical components. For example, a 30 kw. 500-cycle alternator that weighs 75 lb. is shown in Fig. 8. This weighs approximately 2.5 lb. per kw. and is approximately 60 percent of the weight of an equivalent d.c. machine. Fig. 9 shows the potential weight of the alternators at higher ratings.

Relays and circuit breakers for the a.c. system have weights as low as five percent of their commercial equivalent. It is significant that this reduction in size and weight is not due to the use of 400 cycles, but to efficient design. For the first time a customer needed a relay that was small and compact and would still handle considerable power. Ingenious design produced it.

The probable weight of 400-cycle induction motors for various horsepowers is shown by Fig. 10. Careful design avoids low power factor, and both efficiency and power factor are comparable to that of the much larger 60-cycle motors.

Engineering knowledge and techniques that made possible the many highly efficient designs of electrical devices for aircraft may serve in other fields. In addition to much new basic design knowledge, industry now has several new constant speed drives that may improve automobiles, servomechanisms, and other products.

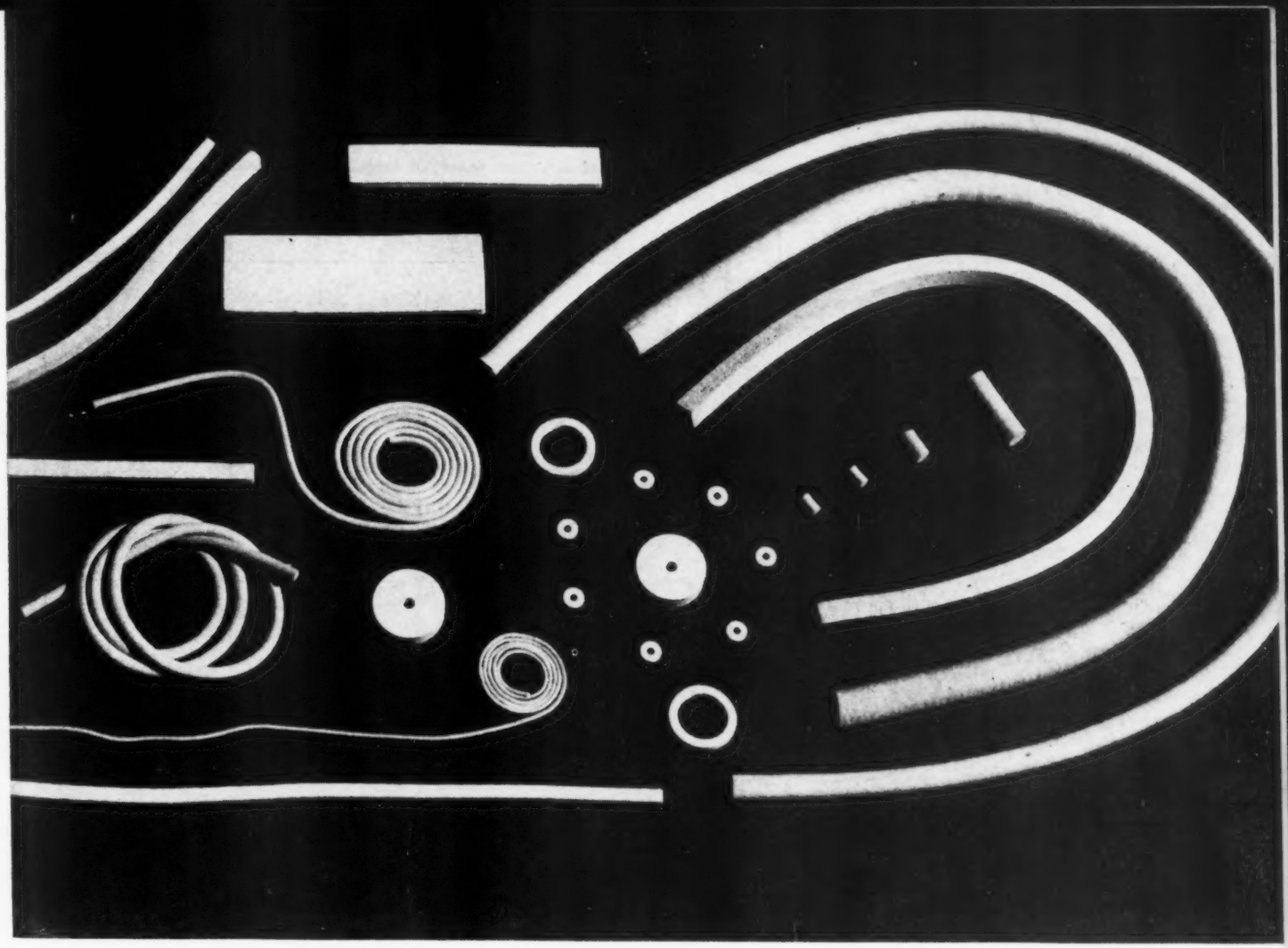
## Dielectric Plastic Film

IMPROVEMENT of plastic films, such as cellulose acetate, for use as capacitor dielectrics was made in Germany by loading the films with ceramic powder.

A satisfactory, elastic film for capacitor dielectrics reportedly has been developed by this company by combining 200 parts of a ceramic powder known as "Lutz No. 105" with 100 parts of cellulose triacetate at a temperature of 160 degrees Centrigrade.

"Lutz No. 105" is composed of 95.9 per cent rutile, 4 per cent lanthanum oxide hydrate, and 0.1 per cent of beryllium carbonate. It is claimed to have a permittivity value of 94 and a power factor of 0.00065.

For preparation of film, "Lutz No. 105" is prepared in an organic suspension. "Igelit" polyvinyl chloride, manufactured by the I. G. Farbenindustrie. The finished film reportedly has a dielectric constant of 10. Its softening temperature is about 80 or 90 degrees Centrigrade.



# Felt Wick Lubricating Systems For Bearings and Machine Parts

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**Oil absorption and storage capacity, wick rise rate and wick delivery rate of standard SAE felts when used in syphon and bottom feed lubrication systems are discussed and evaluated. Selection chart gives properties of wick felt with recommended applications. Methods are described for controlling feed rate or fluid delivery.**

Wick feed lubricating systems deliver oil or other fluids to friction areas of bearings and other mechanical parts that are either adjacent to or remote from the supply reservoir. When correctly designed this type of lubricator performs automatically and efficiently without failure or interruption. Four general types of felt lubricators are used in machinery: Bottom wick, syphon wick, absorbent or pad, and top feed.

Syphon and pad feed systems are the most widely used although bottom wick lubricators are generally considered the most efficient. Bottom wick lubricators are entirely automatic, require no attention other than occasional cleaning, and allow a return of the unused oil or fluid to the reservoir. In top feed oilers, consisting of a reservoir with a wick extending from a bottom outlet, the wick is only a semi-controlled obstruction. In all applications, the type of lubricating system to be used is that which satisfies both the design and the operating conditions.

In the selection of the proper wick materials as much care is required as is exercised in the selection of the lubricant. All wick

feed lubricating systems require a wick material of high absorption capacity. But in addition, for uninterrupted and uniform service, the properties of controlled porosity, wick rise rate, delivery, wick density and size, fiber quality and acid neutrality must also be considered. Acid neutrality is necessary to prevent the corrosion of adjacent metal parts or the possible cracking of lubricant. A highly cohesive wick material made from fibers of medium-to-long length and having a low residual ash content, to minimize glazing or scoring, is necessary to prevent fiber disintegration and subsequent clogging at the lubricating point.

### Wick Design Data

Extensive physical and chemical testing has proved that certain mechanical grades of felt completely fulfill the basic requirements of a satisfactory wick material. Grades found to be suitable are those manufactured in conformance with SAE Standard F-1, F-5, F-10, and F-50 material specifications. The wick design data reported for these felts can be applied to a broad range of materials. But performance values cited in this article for the different grades are limited to the following recommended types:

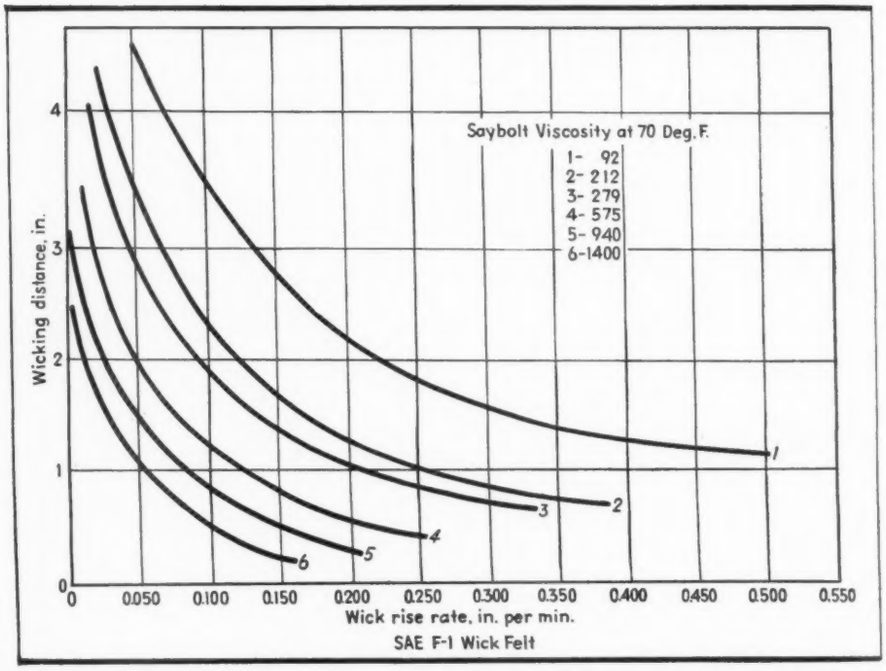


**Fig. 1—Wick rise rate and wicking distance for SAE F-1 wick felts for six oils.**

**Table I—Percent Oil Absorption Capacity of SAE Felts**

Values given are percent weight increase of oil saturated felt as determined by measuring the volumetric displacement of oil of known gravity at 70 deg. F.

| SAE No. | Felt Density percent specific gravity | Viscosity, Saybolt Universal Seconds at 70 deg. F. 92 | 212 | 279 | 575 | 940 | 1,400 |
|---|---|---|---|---|---|---|---|
| | | Specific Gravity 60°/60° F. 0.845 | 0.853 | 0.865 | 0.890 | 0.898 | 0.925 |
| F-1 | 34.2 | 184 | 170 | 189 | 187 | 187 | 190 |
| F-5 | 26.1 | 238 | 225 | 244 | 240 | 241 | 244 |
| F-10 | 18.2 | 427 | 450 | 464 | 456 | 476 | 470 |
| F-50 | 34.2 | 184 | 170 | 189 | 187 | 187 | 190 |

**Table II—Delivery Rates for SAE F-1 Felt Wicks**

Rates given are c.c. per hr. for 0.1 sq. in. cross-sectional area of wick.

| Wicking Distance L, in. | Saybolt Viscosity at 70 Deg. F. 92 | 212 | 279 | 575 | 940 | 1,400 |
|---|---|---|---|---|---|---|
| Syphon Wicks | | | | | | |
| 40 | 6.5 | 2.6 | 1.5 | 0.8 | 0.7 | 0.4 |
| 30 | 5.8 | 2.4 | 1.4 | 0.8 | 0.7 | 0.4 |
| 20 | 5.4 | 2.1 | 1.3 | 0.8 | 0.7 | 0.2 |
| 10 | 4.8 | 2.0 | 1.1 | 0.7 | 0.7 | 0.2 |
| 6 | 4.3 | 1.9 | 1.0 | 0.7 | 0.6 | 0.2 |
| 5 | 3.6 | 1.8 | 0.9 | 0.7 | 0.6 | 0.1 |
| 4 | 3.0 | 1.7 | 0.9 | 0.6 | 0.4 | 0.1 |
| 3 | 2.1 | 1.4 | 0.8 | 0.6 | 0.4 | 0.1 |
| 2 | 1.4 | 1.1 | 0.7 | 0.5 | 0.2 | ... |
| 1 | 0.7 | 0.7 | 0.4 | 0.3 | 0.1 | ... |
| Bottom Wicks | | | | | | |
| −1 | 25.6 | 12.8 | 8.7 | 3.6 | 2.9 | 1.8 |
| −2 | 10.7 | 8.2 | 5.7 | 2.1 | 1.3 | 0.6 |
| −3 | 7.3 | 5.6 | 3.7 | 1.1 | 0.4 | ... |
| −4 | 5.0 | 3.2 | 2.3 | 0.4 | ... | ... |
| −5 | 3.2 | 1.6 | 1.1 | ... | ... | ... |
| −6 | 1.8 | ... | ... | ... | ... | ... |

| Felt Grade | Wick Type |
|---|---|
| SAE F-1 | Round, strip, and punched |
| SAE F-5 | Strip, washer, and absorbent pad |
| SAE F-10 | Absorbent pad and washer |
| SAE F-50 | Ball bearing absorbent seals. |

Absorption Capacity. Satisfactory wick materials must exhibit a high degree of oil absorption and storage capacity. SAE F-1 felt, of controlled density in relation to absorption capacity for maximum wick rise rate, and SAE F-5, F-10, and F-50 completely satisfy this primary requirement. Absorption capacity depends basically on felt density. As indicated in Table I, the absorption capacity increases in direct inverse proportion to density.

Wick Rise Rate. Wick rise rate of felt is defined as the rate of vertical capillary rise of a fluid in inches per minute at a specified wicking distance. Both wick rise rate, or capillarity, and the distance to which oil can be delivered to a remote friction point increase with felt density. They also vary in direct inverse proportion to fluid viscosity. Figs. 1 to 3 give the wick rise rate and the wicking distance of three standard wick felt qualities with oils of different viscosities. Examination of the characteristics of these curves explains why it is necessary to specify a felt of equivalent density to SAE F-1 when oil is to be

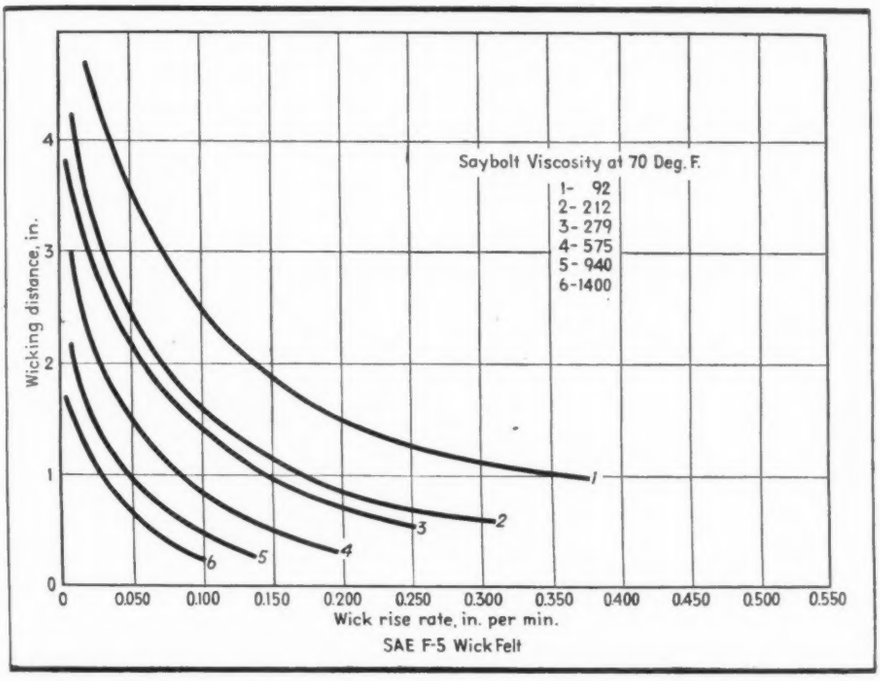


**Fig. 2—Wick rise rate and wicking ditsance for SAE F-5 wick felts for six oils.**

delivered a considerable distance to a remote friction point.

Wick rise rate is not affected by the direction in which a wick is cut or drilled from felt. The random but uniform distribution of fiber in the material is largely responsible for this distinctive property of felt wicks. Wick rise rate and wicking distance are also independent of wick size or cross-sectional area. This characteristic in relation to selected wick rise rate and volume absorption capacity makes possible the dimensioning of felt wicks to obtain a predetermined feed or oil delivery rate.

Wick Delivery Rate. Oil feed or delivery rate of a felt wick is determined by its absorption capacity in relation to its wick rise rate and cross-sectional area. Since both wick rise rate and absorption capacity are functions of density, fiber quality, blend, and uniformity of construction, these properties must be controlled as they are in SAE F-1, F-5, F-10, and F-50 grades for optimum performance when used for wick.

The comparative delivery rates for bottom and syphon feed wicks of SAE F-1 quality felt given in Table II apply to oils at 70 deg. F. and of rated Saybolt viscosity. These data have been established from tests that simulated actual feed lubricating systems. The tests were performed with wicks of different cross-sectional area and the results indicated that wick delivery rate is directly proportional to area. Delivery rates were measured by maintaining a constant reservoir level and computing the rate of feed from a metering burette.

The test observations covered a complete range of commercial grade lubricating oils with viscosities ranging from 92 to 1,400 Saybolt Universal seconds at 70 deg. F. With wicks in direct contact with the journal and at all journal speeds between 100 and 3,600 r.p.m., the delivery rates were constant when the oil delivered to the journal was removed instantaneously from the journal. To make it useful for estimating the delivery rates for wicks of any area, Table II gives averaged data on a unit basis of c.c. of oil per hr. per 0.10 sq. in. of cross-sectional area. Conversions from c.c. to drops of oil can be made by using the relation that 1 c.c. equals 30 drops of oil. Approximations of delivery rates at operating temperatures other than 70 deg. F. can be made by referring to Fig. 4, which gives viscosity and temperature relation for oils of six different viscosities.

Example. Oil of 575 Saybolt viscosity at 70 deg. F. has a delivery rate of 3.6 c.c. per hr. at a bottom wicking distance of 1 in. (Table II). At an operating temperature of 100 deg. F. what is the comparative delivery rate for this oil? From Fig. 4, the viscosity of this oil is found to be 220 at 100 deg. F. This, from Fig. 4, is comparable

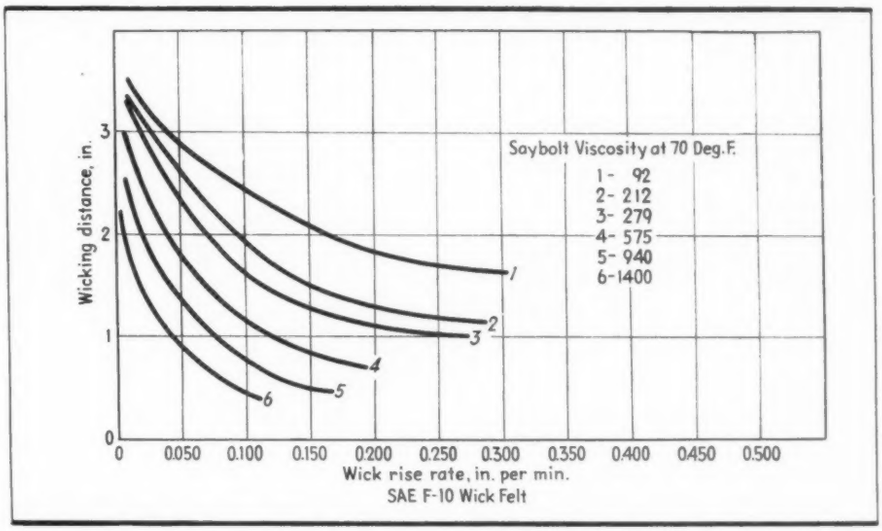


**Fig. 3—Wick rise rate and wicking distance for SAE F-10 wick felts for six oils.**

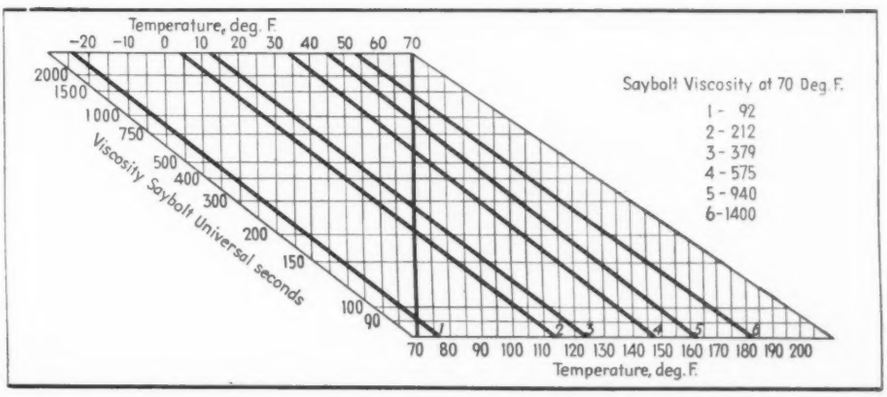


**Fig. 4—Viscosity-temperature conversion chart for six oils of different viscosities.**

to oil of 212 Saybolt viscosity at 70 deg. F., and from Table II, a delivery rate of 12.8 c.c. per hr. at an equivalent bottom wicking distance of 1 inch.

When comparing the difference in performance of bottom and syphon wicks, it should be noted that bottom wicks, although limited in wicking distance to a maximum of approximately 6 in., provide the greatest delivery within this distance. The delivery rate of bottom feed wicks increases with proximity to the journal or friction point, whereas the reverse is true of vertical syphon wicks. This is attributed to a reversal of inter-fibrillar resistance in relation to capillarity and to the effect of gravity or capillary hydraulic head.

Theoretical Delivery Rate. The delivery or wick feed rate of any felt quality of known density, wick rise rate, and absorption capacity can be calculated for any fluid of known gravity from a formula derived from experimental observations and test data, in which

$Q$ = delivery rate, c.c. per hr.
0.8 = average coefficient of capillarity
$D$ = density of felt, grams per cu. in.
$= \frac{\text{percent specific gravity}}{100} \times 16.4$
$C$ = absorption capacity of felt, percent
$A$ = cross-sectional area of wick, sq. in.
$R$ = wick rise rate, in. per min. at specified wicking distance
$G$ = specific gravity of fluid
60 = conversion from c.c. per min. to c.c. per hr.

$$Q = \frac{0.8 \times 60\ DCAR}{G}$$

Example. A delivery rate of 240 drops per hr. is required from a bottom wick oiler using an oil of 212 Saybolt viscosity at 70 deg. F. The specified wicking distance from the bottom of the shaft to the oil level of the reservoir is 1-½ in. A square wick of SAE F-5 density is to be used.

Solution:

$Q = 240/30 = 8.0$
$G = 0.853$, from Table I
$D = \frac{26.1 \times 16.4}{100} = 4.28$
$C = 225$ percent, from Table I
$R = 0.108$ in. per min., from Fig. 2.

The required cross-sectional area and size of a wick of F-5 density and quality will be

$$A = \frac{Q \times G}{0.8\ D \times C \times R} \times \frac{1}{60}$$
$$= \frac{8.0 \times 0.853}{0.8 \times 4.28 \times 2.25 \times 0.108} \times \frac{1}{60}$$
$$= 0.137 \text{ sq. in.}$$

The required wick size is therefore approximately ⅜ in. square to provide a delivery rate of 240 drops per hr. at a wicking distance of 1-½ inches.

Selection. The selection of the proper wick felt quality for any individual application is best determined by actual performance testing. Experience indicates that certain grades are more suitable for distinct classes of lubrication service, but in general.

1. If the felt is to be used in a bottom or syphon feed wick lubricating system where delivery is to a remote friction point, or if a round drilled wick is needed, a high density standard wick felt quality with maximum wick rise rate and wicking distance is recommended.

2. If the felt is to be used as a saturated reservoir within an inclosed bearing or journal box, or if it is to be used as an absorbent pad or strip oiler, a low density standard wick felt quality with maximum absorption and storage capacity is recommended.

Wick felts of SAE F-1 density should be selected for all bottom, syphon, and round wick applications. Wick felts of SAE F-5 density and wick felts of SAE F-10 density are preferred grades for use in conjunction with strip, washer, and absorbent pad feed oilers. For thin reservoir retainers assembled within inclosed bearings, SAE F-50 of equivalent density and quality to SAE F-1 is preferable because of its extreme fineness, cohesiveness, and dimensional accuracy. The wick felt selection chart, Table III, includes recommended wick felt qualities.

Application. The application of felt wicks to lubricating systems is not limited by special precautions or design considerations. Selection having been made in accordance with the recommendations set forth in Table III, the feed rate or fluid delivery for any application can be controlled by adjustments of:

1. Wicking Distance. (A) To increase or decrease the fluid feed rate of syphon wicks, respectively increase or decrease the wicking distance. (B) To increase or decrease the fluid feed rate of bottom wicks, respectively decrease or increase the wicking distance.

2. Wick Diameter. To increase or decrease the fluid feed rate of syphon, bottom, or pad wicks, respectively increase or decrease their cross-sectional area or diameter.

3. Wick Restriction. To retard the fluid feed rate of syphon, bottom, or pad wicks, restrict the flow by mechanically clamping or compressing a section of the wick at a point between the reservoir and the delivery end of the wick.

Round or drilled wicks are available in diameters ranging from 3/64 to 1 in. Square, strip, punched, washer, or pad feed wicks can be furnished to meet practical dimensional and performance tolerances. Before installation, all wicks should be presaturated with oil of the grade to be used as a lubricant. Wick retainer tubes should be large enough not to crowd the wick and excessive spring pressure should be avoided on unretained contact wicks, because either would cause a retardation of the normal delivery of the wick and possibly result in surface glazing.

Typical applications of felt wicks with fluids other than oil include the use of felt as a carrying agent for fluids and impregnants such as water, ink, and process fluids in automatic printing equipment, numbering machines, and postage meters. Felt wicks and plugs when saturated with oil and inserted into coil springs, such as helical valve springs for aircraft engines, lubricate and guard vital machine parts against corrosion and frictional wear. In addition, felt can be impregnated with grease, glycerine, dispersions of micronized graphite, tallow, hydrogenated and sulphonated oils, silicone greases or with different types and hardnesses of wax. When so treated, felts provide an auto-lubricating part for a variety of mechanical movements.

The first cost of felt wicking should not be given first consideration. Selection of wicking on the basis of performance will insure long life, without failure or interruption, and afford more economical machine operation at low maintenance cost.

**Table III—Wick Felt Selection Chart**

| Property | SAE Standard F-1 | F-5 | F-10 | F-50 |
|---|---|---|---|---|
| Density, percent specific gravity | 34.2 | 26.1 | 18.2 | 34.2 |
| Tensile strength, lb. per sq. in. | 500 | 400 | 225 | 500 |
| Thickness, in. | 0.125—1.000 | 0.125—1.000 | 0.125—1.000 | 0.045—0.095 |
| Wick property rating: | | | | |
| Wicking distance | Excellent | Good | Fair | Excellent |
| Wick rise rate | Excellent | Good | Fair | Excellent |
| Absorption capacity | Good | Good | Excellent | Good |
| Delivery rate | Excellent | Excellent | Excellent | Excellent |

Recommended Applications:

SAE F-1. Round, square, punched, or strip wicks for bottom or syphon wick feed lubricating systems and proximate or remote delivery.

SAE F-2. Square, punched, or strip wicks for bottom or syphon wick feed lubricating systems and proximate delivery. Also absorbent pad oilers.

SAE F-10. Absorbent pad wick oilers for maximum storage capacity.

SAE F-50. Oil retainers for inclosed or sealed ball bearings.

# Four Methods for the Solution Of Simultaneous Linear Equations

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**Solution of simultaneous linear equations by methods based on elimination, matrices, a tabular technique, and relaxation. Calculation forms are given for the practical computer. A brief review of some properties of matrices is included. Operational procedure is illustrated with the solution of two sets of equations containing four unknown values.**

MANY PROBLEMS arise in the engineering office that contain as their essence the solution of $n$ linear equations in $n$ unknowns. Such problems are encountered in the solution of indeterminate structures, electrical circuits and the whole class of physically significant problems known as boundary value problems of differential equations.

The aim of this discussion is to give forms for the applied calculation. The use of a calculating machine is assumed available. Since the form of the calculation is decisive for the practical computer, considerable attention should be given to it. As a general principle, in the operation of solving any particular problem unnecessary writing should be avoided.

## METHOD BASED ON ELIMINATION

EXAMPLE 1. A set of four equations used by Crout will be used as an example. (Crout, Prescott D. "A Short Method for Evaluating Determinants and Solving Systems of Linear Equations with Real or Complex Coefficients," A.I.E.E. *Transactions*, Vol. 60, 1941).

$$\begin{aligned} 12.1719w + 27.3941x + 1.9827y + 7.3757z &= 6.6355 \\ 8.1163w + 23.3385x + 9.8397y + 4.9474z &= 6.1304 \\ 3.0706w + 13.5434x + 15.5973y + 7.5172z &= 4.6921 \\ 3.0581w + 3.1510x + 6.9841y + 13.1984z &= 2.5393 \end{aligned}$$

In proceeding with the solution each equation is divided through by its leading coefficient, giving the following array of coefficients and constant terms. Only the coefficients are retained, the unknowns being omitted since their positions indicate their meaning. The constants are kept in the right-hand column.

| | | | | |
|---|---|---|---|---|
| 1 | 2.250602 | 0.162892 | 0.605961 | 0.545149 |
| 1 | 2.875510 | 1.212338 | 0.609563 | 0.755320 |
| 1 | 4.410669 | 5.079561 | 2.448121 | 1.528073 |
| 1 | 1.030378 | 2.283804 | 4.315882 | 0.830352 |

The first equation is subtracted from each of the remaining, giving:

| | | | | |
|---|---|---|---|---|
| 1 | 2.250602 | 0.162892 | 0.605961 | 0.545149 |
| 0 | *0.624908* | *1.049446* | *0.003602* | *0.210171* |
| 0 | *2.160067* | *4.916669* | *1.842160* | *0.982924* |
| 0 | *−1.220224* | *2.120912* | *3.709921* | *0.285203* |

Numbers in italics constitute a set of three equations in three unknowns. The same technique as just used is then applied to these. Proceeding in this way, the following is obtained at the fifth step.

| | | | | |
|---|---|---|---|---|
| 1 | 2.250602 | 0.162892 | 0.605961 | 0.545149 |
| 0 | 1 | 1.679361 | 0.005764 | 0.336323 |
| 0 | 0 | 1 | 1.419329 | 0.198926 |
| 0 | 0 | 0 | 1 | 0.060838 |

Then $z = 0.060838$

Substituting this value of z in the third equation gives

$$y = 0.198926 - 1.419329\ (0.060838) = 0.112577$$

Substituting y and z in in the second equation, and so on. finally gives

$$w = 0.1593 \qquad y = 0.1126$$
$$x = 0.1469 \qquad z = 0.0608$$

This process, though laborious, is routine. It may be made somewhat easier by omitting to write down the coefficients that do not change at each step.

## MATRIX METHOD

The process is simply illustrated by use of the equations of Example (1). The Matrix A is the matrix of coefficients of the equations of Example (1). As indicated, Matrix A is subjected to a series of "row manipulations," the total result of which is to convert it into an Identity Matrix I. Simultaneously the same set of manipulations will be performed on an auxiliary matrix, which is also an identity matrix.

| Matrix *A* | | | | Matrix *I* | | | |
|---|---|---|---|---|---|---|---|
| 12.1719 | 27.3941 | 1.9827 | 7.3757 | 1 | 0 | 0 | 0 |
| 8.1163 | 23.3385 | 9.8397 | 4.9474 | 0 | 1 | 0 | 0 |
| 3.0706 | 13.5434 | 15.5973 | 7.5172 | 0 | 0 | 1 | 0 |
| 3.0581 | 3.1510 | 6.9841 | 13.1984 | 0 | 0 | 0 | 1 |

Dividing each row by its first element:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2.250602 | 0.162892 | 0.605961 | 0.082156 | 0 | 0 | 0 |
| 1 | 2.875510 | 1.212338 | 0.609563 | 0 | 0.123209 | 0 | 0 |
| 1 | 4.410669 | 5.079561 | 2.448121 | 0 | 0 | 0.325669 | |
| | 1.030378 | 2.283804 | 4.315882 | 0 | 0 | 0 | 0.327000 |

Subtracting the first row from the remaining rows:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2.250602 | 0.162892 | 0.605961 | 0.082156 | 0 | 0 | 0 |
| 0 | *0.624908* | *1.049446* | *0.003602* | *−0.082156* | *0.123209* | 0 | 0 |
| 0 | *2.160067* | *4.916669* | *1.842160* | *−0.082156* | 0 | *0.325669* | 0 |
| 0 | *−1.220224* | *2.120912* | *3.709921* | *−0.082156* | 0 | 0 | *0.327000* |

The numbers in italics represent three by three matrices that are

dealt with in the same manner. Proceeding in this way, after five steps the following arrays are achieved:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2.250602 | 0.162892 | 0.605961 | 0.082156 | 0 | 0 | 0 |
| 0 | 1 | 1.679361 | 0.005764 | −0.131469 | 0.197163 | 0 | 0 |
| 0 | 0 | 1 | 1.419329 | 0.156559 | −0.330365 | 0.252626 | 0 |
| 0 | 0 | 0 | 1 | 0.406689 | −0.7344962 | 0.478462 | −0.148514 |

There has now been obtained a "diagonal" form that has zeros below the main diagonal on the left and zeros above it on the right. The succeeding manipulations are designed to remove zeros above the diagonal on the right and attain zeros there in the left.

Subtracting 2.250602 times the second row from the first:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0 | −3.616681 | 0.592989 | 0.378040 | −0.443735 | 0 | 0 |
| 0 | 1 | 1.679361 | 0.005764 | −0.131469 | 0.197163 | 0 | 0 |
| 0 | 0 | 1 | 1.419329 | 0.156559 | −0.330365 | 0.252626 | 0 |
| 0 | 0 | 0 | 1 | 0.406689 | −0.734962 | 0.478462 | −0.148514 |

Subtracting 1.679361 times the third row from the second:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0 | −3.616681 | 0.592984 | 0.378040 | −0.443735 | 0 | 0 |
| 0 | 1 | 0 | −2.377802 | −0.394388 | 0.751965 | −0.424250 | 0 |
| 0 | 0 | 1 | 1.419329 | 0.156559 | −0.330365 | 0.252626 | 0 |
| 0 | 0 | 0 | 1 | 0.406689 | −0.734962 | 0.478462 | −0.148514 |

After four such steps the following is obtained:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | −1.384538 | 2.570015 | −1.826125 | 0.850428 |
| 0 | 1 | 0 | 0 | 0.572638 | −0.995629 | 0.713438 | −0.353137 |
| 0 | 0 | 1 | 0 | −0.420666 | 0.712788 | −0.426469 | 0.210790 |
| 0 | 0 | 0 | 1 | 0.406689 | −0.734962 | 0.478462 | −0.148514 |

The last result on the left is seen to be Matrix *I*, and it indicates that the process is finished. The last result on the right is the desired matrix. Using the rules of matrix multiplication and multiplying the matrix on the right by the single-columned matrix formed by the constants of Example I:

$$\begin{bmatrix} 6.6355 \\ 6.1304 \\ 4.6921 \\ 2.5393 \end{bmatrix}$$

gives the set of solutions as the final matrix:

$$\begin{bmatrix} 0.15925 \\ 0.14694 \\ 0.11257 \\ 0.06084 \end{bmatrix}$$

These, to four decimal places, agree with the previous results obtained by the method based on elimination. The work of finding the desired matrix as outlined can obviously be simplified during the actual computation by omitting to rewrite at each step any numbers that remain unchanged in that step.

In reference to the solution just performed on the single-columned matrix formed by the constants of Example I, a short review of the properties of matrices is necessary. Matrices can be multiplied together, although order of multiplication affects the result. For example, if A and B are matrices, $A \times B$ is not equal to $B \times A$ in general. Matrix multiplication can be illustrated using the special case of a 3 by 3 square matrix multiplied on the right by a 3 by 2 rectangular matrix. Note that the number of columns of the first matrix must equal the number of rows of the second matrix.

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \times \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \\ b_{31} & b_{32} \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \\ c_{31} & c_{32} \end{bmatrix}$$

where

$$c_{11} = a_{11}b_{11} + a_{12}b_{21} + a_{13}b_{31}$$
$$c_{12} = a_{11}b_{12} + a_{12}b_{22} + a_{13}b_{32}$$

and so on. In general

$$c_{ij} = \sum_k a_{ik}b_{kj}$$

This may be made clearer by recourse to a corresponding numerical example:

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix} \times \begin{bmatrix} 1 & 2 \\ 3 & 0 \\ 1 & 1 \end{bmatrix} = \begin{bmatrix} 10 & 5 \\ 25 & 14 \\ 40 & 23 \end{bmatrix}$$

where

$$10 = 1 \times 1 + 2 \times 3 + 3 \times 1$$
$$14 = 4 \times 2 + 5 \times 0 + 6 \times 1$$

and so on.

This method is desirable where more than one set of constant terms occur alternately on the right of equations and the left side meanwhile remains the same. Thus, the different sets of constants need only enter the calculation at the last step. In indeterminate structure problems, the right-hand sides of the equations usually represent functions of the loads alone, while the left-hand sides are functions of the structure alone. Thus a structure can be solved under several loading conditions with little additional work.

## CROUT'S METHOD

A method developed by P. D. Crout has been of value in practice. The method makes use of matrix notation and terminology, but requires no knowledge of matrix or determinant technique. It has a single distinct advantage in its use with a computing machine, that is, it permits continuous machine operations without the tentative writing down of intermediate results. The method is largely concentrated in the determination of an "auxiliary" matrix. Considering the coefficients and constant terms of Example (1) as the given matrix, the solution requires the formation of one auxiliary matrix and a set of final results from the auxiliary matrix.

The procedure for obtaining the auxiliary matrix from the given matrix is contained in the following rules.

1. The several numbers, or elements, are determined in the following order: Elements of first column, then elements of first row to right of first column; elements of second column below first row, then elements of second row to right of second column; elements of third column below second row, then elements of third row to right of third column; and so on until all elements are determined.

2. The first column is identical with the first column of the given matrix. Each element of the first row, except the first, is obtained by dividing the corresponding elements of the given matrix by that first element.

3. Each element on or below the principal diagonal (longest diagonal, starting at upper left hand corner) is equal to the corresponding element of the given matrix minus the sum of those products of elements in its row and corresponding elements in its column (in the auxiliary matrix) that contain only previously computed elements.

4. Each element to the right of the principal diagonal is given by a calculation that differs from Rule 3 only in that there is a final division by its diagonal element in the auxiliary matrix.

For convenience, Example (1) will be used again. In the following typical calculations for the auxiliary matrix, the letters *R* and *C* represent the words "row" and "column," respectively:

*R1C3* 0.16289 = 1.9827 ÷ 12.1719

*R2C2* 5.0720 = 23.3385 − 8.1163 × 2.2506

*R4C2* −3.7316 = 3.1510 − 3.0581 × 2.2506

*R2C5* 0.33632 = (6.1304 − 8.1163 × 0.54515) ÷ 5.0720

*R3C3* 3.9585 = 15.5973 − 3.0706 × 0.16289 − 6.6327 × 1.6793

*R4C3* 12.7526 = 6.9841 − 3.0581 × 0.16289 + 3.7316 × 1.6793

*R3C4* 1.4193 = (7.5172 − 3.0706 × 0.60596 − 6.6327 × 0.0057629) ÷ 3.9585

*R4C4* −6.7332 = 13.1984 − 3.0581 × 0.60596 + 3.7316 × 0.0057629 − 12.7526 × 1.4193

*R4C5* 0.060806 = (2.5393 − 3.0581 × 0.54515 + 3.7316 × 0.33632 − 12.7526 × 0.19891) ÷ (−6.7332)

The completed auxiliary matrix is the 4 by 5 matrix:

| | | | | |
|---|---|---|---|---|
| 12.1719 | 2.2506 | 0.16289 | 0.60596 | 0.54515 |
| 8.1163 | 5.0720 | 1.6793 | 0.0057629 | 0.33632 |
| 3.0706 | 6.6327 | 3.9585 | 1.4193 | 0.19891 |
| 3.0581 | −3.7316 | 12.7526 | −6.7332 | 0.060806 |

The procedure for obtaining the one-column final matrix (solutions) from the auxiliary matrix is contained in the following rules:

1. The elements are determined in the following order: Last, next to last, second from last, third from last, and so forth.

2. The last element is equal to the corresponding element in the last column of the auxiliary matrix.

3. Each element is equal to the corresponding element of the last column of the auxiliary matrix minus the sum of those products of elements in its row in the auxiliary matrix and corresponding elements in its column in the final matrix that contain only previously computed elements.

In forming products only those elements of the auxiliary matrix are used that lie to the right of the principal diagonal and to the left of the last column. The calculations for the final matrix are

$$R3C1 \quad 0.11261 = 0.19891 - 1.4193 \times 0.060806$$

$$R2C1 \quad 0.14687 = 0.33632 - 1.6793 \times 0.11261 - 0.0057629 \times 0.060806$$

$$R1C1 \quad 0.15942 = 0.54515 - 2.2506 \times 0.14687 - 0.16289 \times 0.11261 - 0.60596 \times 0.060806$$

This procedure has been summarized in tabular form by R. C. Veit ("A Short Method of Solving Simultaneous Linear Equations," Republic Aviation Corporation) for use on a set of five equations in five unknowns. The scheme of operations shown in the chart (below), which summarizes this technique, can be extended to more unknowns or reduced to fewer by application of the rules.

The solutions of Example (1), to four decimal places, are seen to be

$$w = 0.1594$$
$$x = 0.1469$$
$$y = 0.1126$$
$$z = 0.0608$$

These values for terms agree well with the previous results.

## RELAXATION METHOD

This method can be systemized to work rapidly on a set of n equations in n unknowns when the set is characterized by predominant diagonal terms. Such sets occur frequently in practice.

EXAMPLE 2.

$$30.7198w + 2.1037x + 1.0665y + 0.9038z = 61.5197$$
$$0.2066w + 51.2328x + 2.7651y + 1.9038z = 155.2185$$
$$0.7653w + 2.1732x + 60.5421y + 3.0065z = 247.1113$$
$$1.9187w + 2.5854x + 3.0090y + 70.6531z = 368.7596$$

The solution consists of developing the following tables.

| $R_0$ | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_5$ |
|---|---|---|---|---|---|
| 61.5197 | −15.0160 | 1.4183 | −0.0784 | 0.0121 | −0.0009 |
| 155.2185 | −19.4725 | 0.6259 | −0.1342 | 0.0116 | −0.0015 |
| 247.1113 | −18.1398 | 1.5403 | −0.1398 | 0.0161 | −0.0018 |
| 368.7596 | −8.1355 | 2.4550 | −0.2124 | 0.0182 | −0.0023 |

| $w$ | $x$ | $y$ | $z$ |
|---|---|---|---|
| 2.0 | 3.0 | 4.0 | 5.0 |
| −0.50 | −0.37 | −0.30 | −0.11 |
| 0.046 | 0.012 | 0.025 | 0.035 |
| −0.0026 | −0.0026 | −0.0023 | −0.0030 |
| 0.00039 | 0.00023 | 0.00027 | 0.00026 |
| 1.54379 | 2.63963 | 3.72297 | 4.92226 |

The first column in the "R" table is the column of constant terms in the equations of Example (2). By dividing the $R_o$ entries by the corresponding diagonal terms, an approximate set of values is found and recorded in the first row of the "w, x, y, z" table.

Only a rough approximation is required. The values of w, x, y, and z are then substituted in the left hand side of the equations of Example (2) and the results so obtained are subtracted from the corresponding $R_o$'s. These results are recorded as $R_1$'s. Using then the $R_1$'s as new constant terms in place of the $R_o$'s the process is repeated. The new values of w, x, y, and z constitute the second row of the "w, x, y, z" table. The process is continued until the $R$'s are as small as desired, then columns in the "w, x, y, z" table are summed. The sums are the desired solutions.

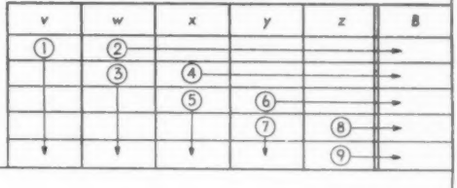
**Given Matrix**

$$\begin{array}{ccccc|c} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & b_1 \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & b_2 \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & b_3 \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & b_4 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & b_5 \end{array}$$

**Scheme for Determining Unknowns From Completed Auxiliary Matrix**

$$v = B_1 - z\,A_{15} - y\,A_{14} - x\,A_{13} - w\,A_{12}$$
$$w = B_2 - z\,A_{25} - y\,A_{24} - x\,A_{23}$$
$$x = B_3 - z\,A_{35} - y\,A_{34}$$
$$y = B_4 - z\,A_{45}$$
$$z = B_5$$

**Scheme for Obtaining Auxiliary Matrix Showing Order of Operations**




**Auxiliary Matrix**

| | | | | | |
|---|---|---|---|---|---|
| $A_{11} = a_{11}$ | $A_{12} = \frac{a_{12}}{A_{11}}$ | $A_{13} = \frac{a_{13}}{A_{11}}$ | $A_{14} = \frac{a_{14}}{A_{11}}$ | $A_{15} = \frac{a_{15}}{A_{11}}$ | $B_1 = \frac{b_1}{A_{11}}$ |
| $A_{21} = a_{21}$ | $A_{22} = a_{22} - A_{12}A_{21}$ | $A_{23} = \frac{a_{23} - A_{13}A_{21}}{A_{22}}$ | $A_{24} = \frac{a_{24} - A_{14}A_{21}}{A_{22}}$ | $A_{25} = \frac{a_{25} - A_{15}A_{21}}{A_{22}}$ | $B_2 = \frac{b_2 - B_1A_{21}}{A_{22}}$ |
| $A_{31} = a_{31}$ | $A_{32} = a_{32} - A_{12}A_{31}$ | $A_{33} = a_{33} - A_{13}A_{31} - A_{23}A_{32}$ | $A_{34} = \frac{a_{34} - A_{14}A_{31} - A_{24}A_{32}}{A_{33}}$ | $A_{35} = \frac{a_{35} - A_{15}A_{31} - A_{25}A_{32}}{A_{33}}$ | $B_3 = \frac{b_3 - B_1A_{31} - B_2A_{32}}{A_{33}}$ |
| $A_{41} = a_{41}$ | $A_{42} = a_{42} - A_{12}A_{41}$ | $A_{43} = a_{43} - A_{13}A_{41} - A_{23}A_{42}$ | $A_{44} = a_{44} - A_{14}A_{41} - A_{24}A_{42} - A_{34}A_{43}$ | $A_{45} = \frac{a_{45} - A_{15}A_{41} - A_{25}A_{42} - A_{35}A_{43}}{A_{44}}$ | $B_4 = \frac{b_4 - B_1A_{41} - B_2A_{42} - B_3A_{43}}{A_{44}}$ |
| $A_{51} = a_{51}$ | $A_{52} = a_{52} - A_{12}A_{51}$ | $A_{53} = a_{53} - A_{13}A_{51} - A_{23}A_{52}$ | $A_{54} = a_{54} - A_{14}A_{51} - A_{24}A_{52} - A_{34}A_{53}$ | $A_{55} = a_{55} - A_{15}A_{51} - A_{25}A_{52} - A_{35}A_{53} - A_{45}A_{54}$ | $B_5 = \frac{b_5 - B_1A_{51} - B_2A_{52} - B_3A_{53} - B_4A_{54}}{A_{55}}$ |

# NEW MATERIALS AND PARTS

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### Hydrogen Thyratrons

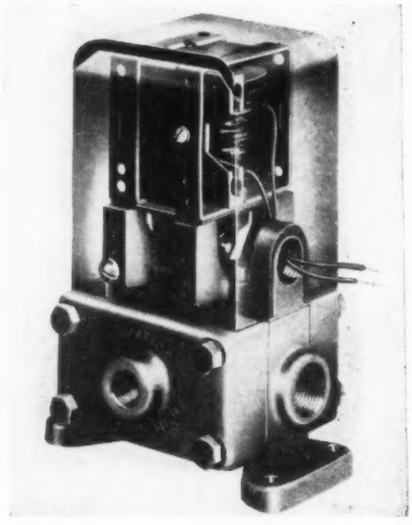
*Sylvania Electric Products, Inc., 500 Fifth Ave., N. Y. 18, N. Y.*

Industrial and communication applications of these units include switching in capacitor discharge welding circuits, shock excitation of tuned circuits; piezoelectric crystal excitation; use in induction heating circuits to replace spark gap heaters; pulse time modulation circuits in which signals are produced by modulating the pulse repetition rate; and servomechanisms where relatively high a.c. supply frequencies are used. Features claimed for these hydrogen thyratrons include low deionization time; rapid switching rates; high peak currents; high plate voltages; moderate trigger requirements; ability to operate at zero bias; operation over wide ambient temperature range; low tube voltage drop; and reliable, flexible operation when mounted in any position.

### Three-Way Valve

*Sumatics, Milford, Mich.*

A solenoid-controlled 3-way valve for compressed air. The solenoid draws less than 3 amp. on 110 volt 60 cycle current. The travel of the plunger is 7/64 in., and this is claimed to eliminate pounding and harsh action. The exhaust port is one pipe-size

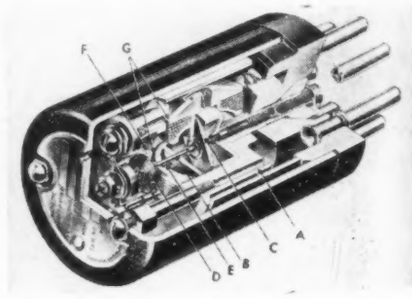


larger than the supply and outlet. The user can select the setup desired by reversing the supply and outlet on the center body—making it open to exhaust and closed to pressure, or open to pressure and closed to exhaust, with the solenoid energized or de-energized. Valve can be mounted in any position. This valve is available in 6 sizes from 1/4 to 1 1/4 in., to handle operating pressures from 0 to 150 pounds.

### Sensitive Magnetic Relay

*Thomas A. Edison, Inc., West Orange, N. J.*

Model 103 relay is for use in the electronic and industrial fields where relays are required for operation on currents of thermocouple and photocell magnitudes. The mechanism is balanced to allow operation in any position. The essential design of this relay is an inversion of the d'Arsonval galvanometer type movement. Two coils are used that can be connected either in series



or differentially so that the relay will operate on the difference between the currents in the two coils. The contacts will handle 1/3 amp. in a non-inductive load circuit; and provide either s.p.s.t. or s.p.d.t. switching. Operating power is normally about 10 microwatts although for some circuit applications operation may be secured with less than 1 microwatt. The coils will dissipate 2 watts, allowing differential operation on large currents. The construction will withstand overloads without damage when used as a simple relay. The magnetic system of the Edison Sensitive Magnetic Relay is inclosed in a highly permeable metal shield (A) which protects it from stray external magnetic fields. Rotor (B) is pivoted in spring-loaded jewel bearings and has a small Alnico vane (C) at its lower end. At its upper end it has a hair-spring (D), a balance cross with weights (E), and a platinum iridum contact arm (F). The magnet vane is positioned between two parallel stationary coils (G) the magnetic fields of which are coincident. The aluminum cover is mounted on a standard small seven-pin radio tube base. The diameter of the unit is 1-1/4 in., its seated height is 2-1/4 in., and its weight is 0.15 pound.

## Potentiometers

*Thomas B. Gibbs & Co., Delavan, Wis.*

The Micropot is linear within 1/10 of one percent. Resistance is directly proportional to shaft rotation over the entire range of a 20,000 ohm unit to within plus or minus 20 ohms. Ten full turns on the standard 1/4 in. shaft drives a sliding contact across more than 40 in. of wire-wound resistance element. The complete potentiometer is 2-1/8 in. in diameter and extends 2-1/8 in. behind the panel. The metal sliding contact is carried on a nut operating along a ground-thread, stainless steel lead screw. Connection to this contact is obtained through a silver disk and two metal contacts. The complete resistance element, with both end terminals soldered in place, is molded as an integral part of the housing to prevent any loosening or shifting of the turns of resistance wire. Running torque is claimed to be less than 1-1/2 in.-oz. at room temperature and not greater than 3 -in.-oz. between −55 deg. and +70 deg. C. Micropots are available in several resistance values from 100 to 100,000 ohms.

## Self-Cleaning Contact for Mixer Control

*Cinema Engineering Co., 1510 W. Verdugo Ave., Burbank, Calif.*

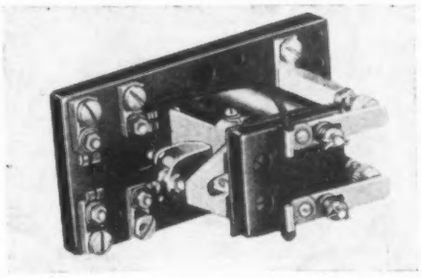
Design makes use of a wedge-shaped roller, riding on a plastic arm and shaft and is claimed to have a brush noise characteristic below the noise level of amplifiers and measuring equipment normally in use in sound laboratories. The signal does not pass through the bearing of the roller contact. In the Variaten mixer control, current passes from the coil to the collector ring directly

through the roller. Advantages claimed for this type of roller contact are: Longer coil life, free operation of the roller brush; self-cleaning wiping action of the roller as it rides between the coil and collector ring; quicker and more accurate adjustment for precision mixing in both recording and re-recording for motion picture, radio and television equipment. This contact arrangement is available with Model Nos. 3182 and 1047, which are supplied with a conventional "ladder" circuit, any conventional input and output impedance, and either of two attenuation characteristics.

## Relays

*Ward Leonard Electric Co., Mt. Vernon, N. Y.*

Designed for electronic applications such as light contactor duty, control of single phase motors and other remote or automatic control purposes, these units have contact arrangements available from one to four poles, normally open or normally closed, single or double-throw. Operating voltages for direct current relays are from 6 to 230 volts and for alternating current from 6 to 440 volts. Relay contact ratings for d.c. are 25 amp. 0-24 volts, 3 amp. 25-125 volts, 1 amp. 125-230 volts and contact ratings for operation on a.c. 60 cycle circuits are 25 amp. 0-250 volts, 15 amp. 251-440 volts. Standard relay features are molded phenolic bases, accessible front connected terminals and corrosion resistant finishes on all metal parts. All sizes of relays have silver to silver contacts. These

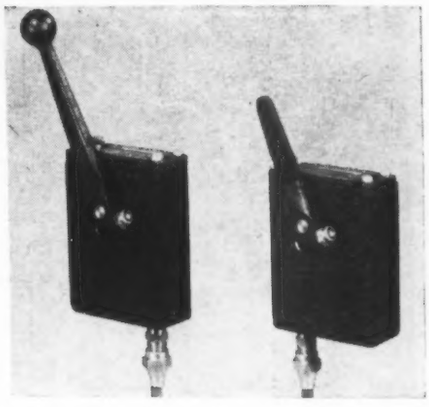


heavy duty relays are manufactured with mechanical interlocks for reversing service and with mechanical latches for manual or electrical.

## Hydraulic Control

*Sperry Products, Inc., Hoboken, N. J.*

This device retains the advantages of larger units in that a single flexible copper tube is used, the system is completely inclosed, and the installation is accomplished with three bolts for each of the two pieces that make up the complete unit. The transmitter and receiver, made of bronze, together weigh 3.7 lb. Any motion of the transmitter



arm will be duplicated by the receiver arm. Either arm will move through an arc of 60 deg. and the receiver arm can be drilled at any location to obtain the desired linear travel of the actuating rod. The complete system is dust-proof and water-proof. Transmitter and receiver can be joined by 35 feet of connecting tubing and lengths longer than that may be used where conditions of temperature and load will permit.

## Amplifier Tube

*Sylvania Electric Products, Inc., Radio Tube Div., 500 Fifth Ave., New York 18, N. Y.*

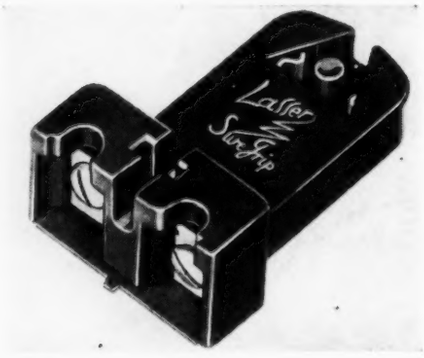
A sharp cut-off r-f pentode amplifier designed for 6.3 volt and a.c. or d.c. series service. The tube can be operated with full plate supply voltage on the screen grid to produce high input resistance as a result of reduced electron transit time. Identical voltage requirements for plate and screen grid also eliminate the need of screen grid filter

resistor and by-pass capacitor in some circuit applications. Direct interelectrode capacitances of this type 7AG7 tube, used with RMA Standard M8-308 shield 1 5/16 in. in diameter and connected to the cathode are: Maximum grid to plate, 0.005 micromicrofarads; input, 7.0 micromicrofarads; and output, 6.0 micromicrofarads. The 7AG7 tube can be operated in any position and is supplied in a T-9 bulb with 8-pin lock-in base. It measures 2 25/32 in. overall and has a maximum diameter of 1-3/16 in. Pin connections conform to RMA basing 8V-L-5.

## Fluorescent Lamp Holder

*Mastercraft Electric Co., 187 Murray St., Newark 5, N. J.*

The Lasser Sure-Grip lamp holder has a contact design that is claimed to provide positive contact under conditions of shock and vibration. Made to permit easy wiring




into fixtures, the body is of durable plastic, and metal inserts precision stamped for uniformity. This lamp holder carries the seal of approval of Underwriters' Laboratories.

## Steel Collars

*Massey Machine Co., 800 Pearl St., Watertown, N. Y.*

Hardened and ground steel collars with hollow head set screws made to the following tolerances: Inside diameter +0.001—0.000; outside dimeter +0.000—0.0002; and width +0.000—0.001 and are available in 32 standard sizes from 1/16 to 2 in. inside diameter in steps of 1/16 inch.

## Control Valves

*Hanna Engineering Works, 1765 Elston Ave., Chicago 22, Ill.*

One type is a packless 1/4 in. capacity valve for tubing and light piping applications. It is designed for 4-way operation, but may be used as a 3-way valve by plugging one port. Suitable for air, oil, or water in pressures to 250 lb. per sq. in. An 80 deg. handle movement gives complete reversal. Available for manifold, column, or panel mounting. The foot-operated valve is a packless control for use in air and oil hydraulic cylinder applications. It is made in two styles—one, with single pedal for constant cycles of operations; and two, with split pedal that holds position until tripped for reversal. Available

in 3/8, 1/2, 3/4 and 1 in. sizes, it operates on 250 lb. per sq. in. air pressure or 1,000 lb. per sq. in. oil pressure. Control of cylinder piston speed in both directions is accomplished by the two-direction speed control valve. It provides for adjustable control of inflow and outflow of air or oil independently to and from one side of the piston. One valve is used for oil operation —two are recommended for air.

## Reflector Floodlight

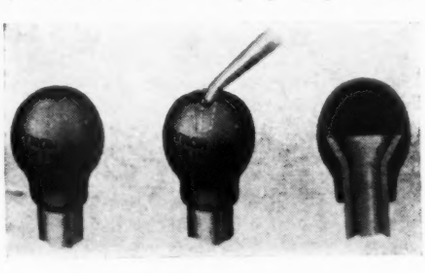
*Wabash Corp., Brooklyn 31, New York.*

Light has a pure-silver reflector lining hermetically sealed inside, and its filament mounted at the focal point. The light beam is moderately concentrated between a 0-60 deg. zone, and the sealed-in silver lining is claimed to keep the bulb at top reflecting efficiency throughout its life, with no loss of illumination by tarnishing of the reflecting surface. The bulb is 5 in. in diameter at its widest point, is 6 1/2 in. in overall length, and can be used in any standard socket, swivel type socket, or ceiling recessed fixture. Four sizes—100, 150, 200, and 300 watts are available, each with an average burning life of one thousand hours.

## Self-Sealing Oil Tube Cap

*Evnon-Dakin Co., 1847 West Bethune Ave., Detroit 6, Michigan.*

The cap, available in colors, is made of molded synthetic Buna "N." It is applied to the slightly flared end of an oil tube or oil line and is permanently fastened by a combination of mechanical interference fit and synthetic cement. It is properly positioned

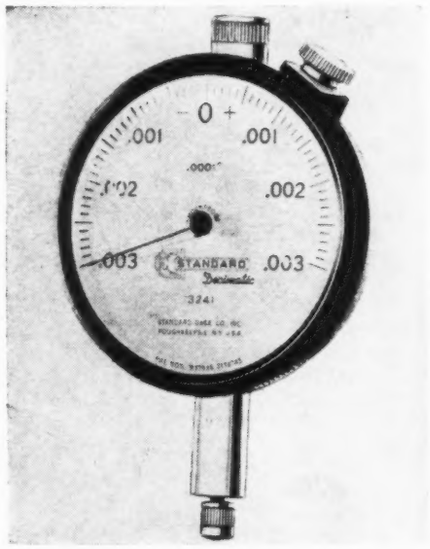


by an internal shoulder that rests on the flared end of the tube. Assembly is easily provided by a threaded tube end, or by a press fit into the bearing housing. Dust and dirt are excluded by the tight sealing of the cap when the oil can spout is removed. No space is required for oiling beyond clearance for the cap. The caps are available for oil tube sizes from 1/8 to 1/2 in outside diameter.

## Indicators

*Standard Gage Co., Inc., Poughkeepsie, N. Y.*

These units have dial markings in decimals and are free from whip and waver. The instruments are claimed to operate under low tension. Mounting dimensions are in accordance with American Gage Design standards and decimatic models may be used in fixtures made to receive AGD indicators.

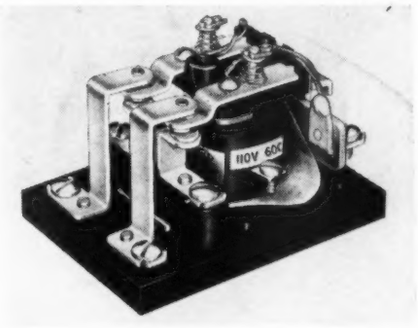



The decimatics differ from AGD specifications in range and in the manner of marking the dial. The decimatic series of indicators comprises 19 different models with a variety of graduation values in both English and metric units.

## Power Relay

*Potter & Brumfield Sales Co., Dept. 231, 549 West Washington Blvd., Chicago 6, Ill.*

A double-pole double-throw power relay (Type PR-8) designed for power circuits to 15 amp. Metal parts are heavily plated for resistance to corrosion, all insulation is molded or laminated bakelite, coils are layer wound on insulating bobbins and baked varnish impregnated. The contact carriers are locked in place and permit heavy contact pressure without chatter. The a.c. types are copper shaded to prevent hum. A heavy return spring provides snap action and the coil operates on 4 volt-amperes or approximately

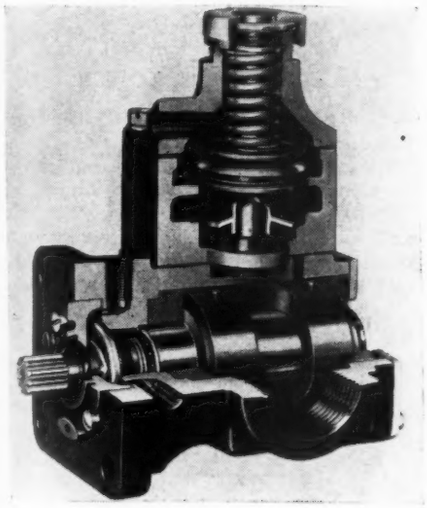



3 watts. Coils will not heat on continuous duty. Silver contact points 5/16 in. in diameter and at 110 volts a.c. are rated at 15 amp. non-inductive load.

## Twin-Valve Pump

*Candler-Hill Corp., Detroit, Mich.*

Pump is claimed to deliver a constant flow of fuel at constant pressure and volume. Working on a common guide pin, the dual valves balance each other and this equal bal-



ance between the machined areas of the two valves is claimed to be superior to the "single valve vs. fabric diaphragm" method of balancing out inlet suction and pressure conditions. The valve is manufactured in two models with respective capacities of 830 and 1,600 gal. per hr. at 2,500 revolutions per minute.

## Linear Potentiometers

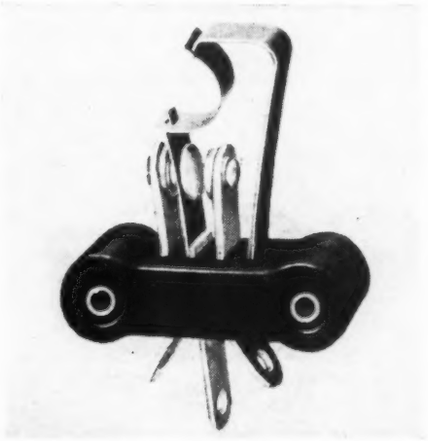
*The Fairchild Camera and Instrument Corp., Jamaica, N. Y.*

Wire-wound linear potentiometers, with accuracies of 0.05 percent claimed in the largest, 5-in. diameter size, and 0.15 percent in the smallest, 2-in. size. The life of these models is claimed to be greater than 1,000,000 cycles of operation while retaining initial accuracies. The torque is claimed to be less than 1 in.-oz. The electrical angle of rotation is from 352 to 357 deg. leaving a maximum unwound sector of 8 deg. in the smallest size and an unwound sector of 3 deg. where the maximum wound length is required.

## Snap Switch

*Arco Electric Co., 1310 Superior Ave., Cleveland 14, Ohio.*

The Model M switch has its operating blade, center blade and rolling spring made of a heat-treated beryllium copper. Overall dimensions are approximately 1 13/32 x 1 1/64 x 5/16 in. Standard operating pres-

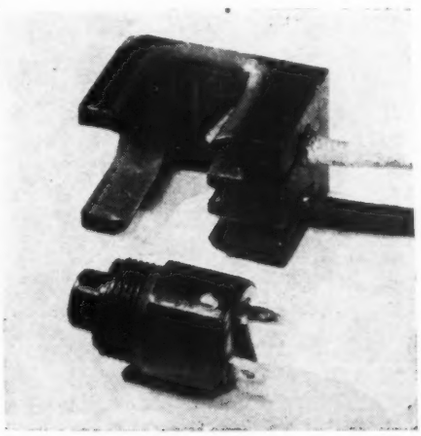


sure is 6 to 10 oz. Rated at 15 amp. 125 volts a.c. and 1/3 h.p. 110 a.c. and furnished for single-pole, normally open, normally closed and double-throw circuits.

## Renewable Switch

*Robert Hetherington & Son, Inc., Sharon Hill, Pa.*

This switch can be used in a single-hole mounting and has two flat studs protruding from the back. Lugs are frequently attached to these. When the switch is used as a renewable type, the studs slide down between two contact bars in the back part of the cradle. The front part of the switch



slides down through a slot in the front part of the cradle. The cradle itself is attached to any flat surface by countersunk screws, and measures an inch long and three-quarters of an inch high. At present only single-pole single-throw switches, either normally open or normally closed, can be furnished in this renewable type.

## Stainless Steel Filter Medium

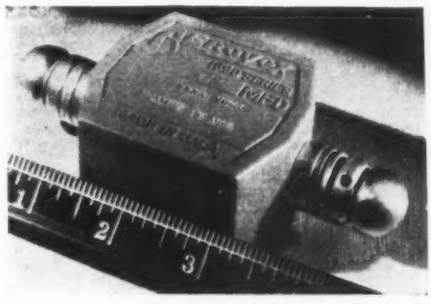
*Micro Metallic Company, 99-16 Metropolitan Ave., Forest Hills, N. Y.*

Filters made from alloyed stainless steel powder, the particles of which are welded together at the points of contact into a porous body, which in the form of thin sheets can be bent about a small radius. It is claimed it can be used as the filter medium or porous element in nearly all types of apparatus. The average pore openings regularly supplied range from 4 to 165 microns (0.00015 to 0.0065 in.).

## Capacitor

*Aerovox Corp., New Bedford, Mass.*

The Aerovox Series 1690 molded-in-bakelite mica capacitor untilizes rounded surfaces to eliminate corona loss; the use of fine threads on the terminal studs for maximum contact; silver plating for all conducting members to minimize skin resistance; and a body of XM or yellow low-loss bakelite. The mica stack is designed for a straight-line path for the ultra-high-frequency current. Body dimensions are 2-3/8x2-3/16x1-3/8 in. and

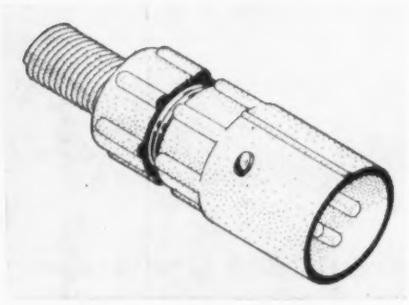


measures 4 3/4 in. overall between rounded terminal tips. Units are available in ratings to 20,000 d.c. test or 10,000 volts operating, and in capacitance values to 0.001 mfd. at the highest voltage rating.

## Electric Connector

*Cannon Electric Development Co., 3209 Humboldt St., Los Angeles 31, Calif.*

A multi-contact electric connector, type "XL," measuring 2 3/32 in. in overall length with a max diameter of 5/8 in. The two plug types weigh 0.0792 and 0.0992 lb. respectively. Removable inserts with tapped metal armor for insert retaining screw, and cable relief spring or removable cable clamp

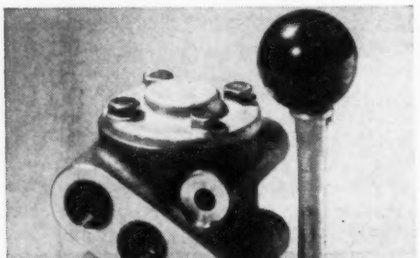


are supplied. Contact No. 1 engages before Nos. 2 and 3 for ground circuits, if desired. A diecast zinc shell with cadmium plate finish, and three 15-amp. silver-plated brass contacts in phenolic insert to accommodate No. 14 B&S stranded wire are furnished.

## Handle-Grip Control

*Pneumatics, Inc., Plymouth, Ind.*

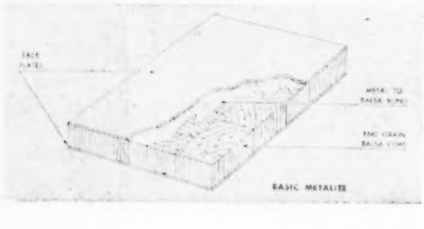
This ½ in., 4-way control valve measures 5 in., x 4 in. x 3 in. and has unrestricted ports. In addition to the handle-grip control, it is available with cam, palm, foot, pilot, and solenoid actuation.



## Structural Material

*Chance Vought Aircraft Div. United Aircraft Corp., Stratford, Conn.*

Metalite is a metal-faced sandwich material with a light-weight core to separate and stabilize the metal faces. It consists of thin sheets of high strength aluminum alloy, separated by a thick, low density core of balsa wood and bonded together to form a single, light, and rigid unit. The grain direction of the balsa core is set perpendicular to the metal faces. A core material of greater density than balsa can be used in spots where greater strength is desired. The core is relatively thick in comparison to the face plates.



## Midget Capacitors

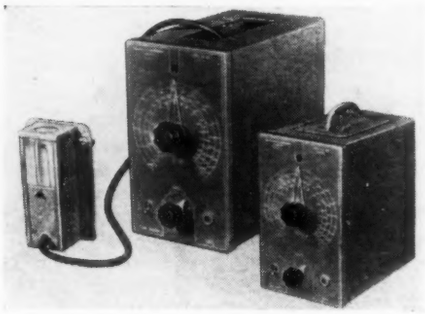
*Stackpole Carbon Co., St. Marys, Pa.*

GA midget capacitors claimed to have advantages of greater stability, better insulation resistance and higher breakdown voltage. Molded with leads anchored and tinned for soldering, they eliminate the inductive characteristic common to twisted wires. They are designed for purposes of neutralization; capacity coupling in antenna, r-f and i-f coils; feedback, r-f by-pass; injection of r-f and audio voltages. Standard capacities include 0.68; 1.0; 1.5; 2.2; 3.3 and 4.7 micro-microfarads. Standard tolerance is ±20 percent.

## Portable Stroboscope

*Communication Measurements Laboratory, 120 Greenwich St., New York 6, N. Y.*

Model 1210 uses a self-blocking oscillator. Rotary or vibratory motion can be "stopped" when the moving object is examined with stroboscopic light source. The speed covered is from 600 to 48,000 r.p.m. (10-800 cycles per second), in 4 ranges. A synchronized reed is provided for accurate calibration against the line frequency. All 4 scales can be calibrated within ±3 percent. The light source is contained in a probe attached to a

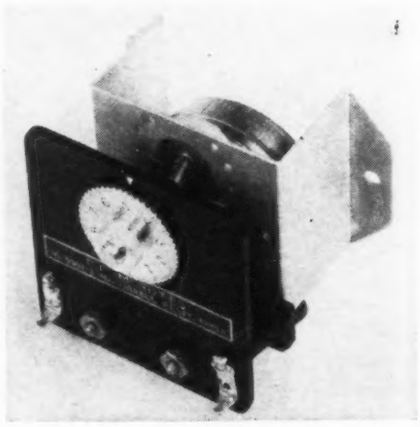


four-foot flexible cable which is stored in the cabinet when the stroboscope is not in use. The unit weighs 19 1/2 lb. and its housing measures 19-1/2 x 5-3/8 x 10-1/2 inches.

## Reset Timer

*Haydon Mfg. Co., Forestville, Conn.*

Unit has either 1/10, 1, or 4 r.p.m. motors giving a range of delay from 1 second to ten minutes. The overall size, including graduation dial and adjustable knob is 3-3/8 x 2-7/8 x 2-7/8 in. Motor has a magnetically controlled clutch that automatically engages the gear train when energized and disengages



when de-energized. When the current is turned off, the drive shaft returns to its starting position by spring action. The motor is furnished with one-way friction to absorb the shock to the gear train at the end of the return travel. The timer switch, normally opened or closed, is rated at 10 amp., 125 volts.

## Shock Resistant Plastic

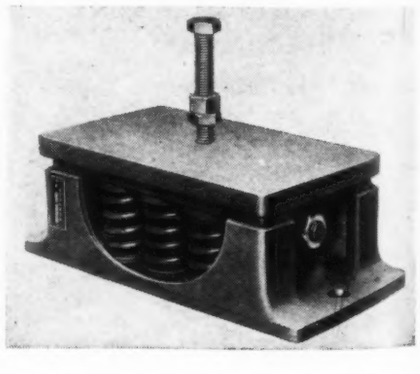
*American Cyanamid Co., 30 Rockefeller Plaza, New York, N. Y.*

Melmac 3020 compound is a rag-filled melamine-formaldehyde molding material and is claimed to be the first thermosetting, shock resistant plastic available in color. Originally designed to combine strength with electrical and chemical resistance properties, this material was supplied in black, and in a mottled white. With color added, this industrial plastic is available for shipment.

## Vibro-Isolator

*The Korfund Co., Inc., 48-15 32nd Place, Long Island City 1, N. Y.*

Type LK, a simplified steel spring vibration isolating unit, is designed in 26 sizes for rated loads of 75-12,000 lb. Adjustable chocks in the four corners of the housing act as stabilizers. Properly installed and adjusted, Type LK provides vibration control for impact machinery, stationary and marine diesel engines, generators, panel boards, ma-



terial testing and processing equipment, ventilating and air conditioning equipment, recording apparatus, business machines, and other industrial equipment.

### Universal Timer

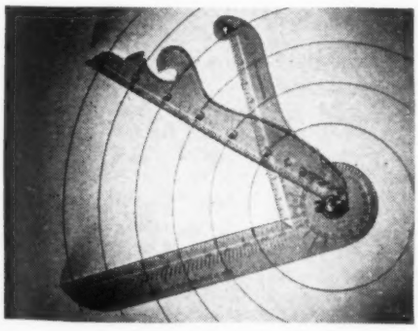
*Gray Laboratory and Mfg. Co., 43 W. Apple St., Dayton 2, Ohio.*

This unit has an 8 in. aluminum dial with second and minute hands and is inclosed in a baked-on enamel case that measures 8½ in. square by 2⅝ in. deep. It operates on 110 volts, 60 cycle current and functions to a maximum load of 750 watts.

### Drafting Instruments

*Parva Products Co., West Haven, Conn.*

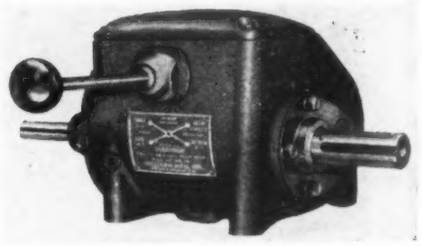
Drawing and measuring instruments of transparent yellow Tenite molded in two parts. It comprises a combination square and removable miter arm, and is designed to perform eight different operations: Square, dividers, protractor, triangle, ruler, French curve, and miter.



### Transmission

*Western Mfg. Co., 3400 Scotten Ave., Detroit 10, Mich.*

The case is provided with four bosses, drilled and tapped, so the transmission can be secured to a plate or flat portion of the machine on which it is to be mounted.

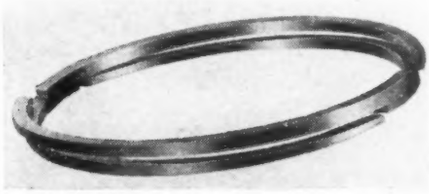


This unit has 5 h.p. capacity with input speed of 900 r.p.m. Four gear changes are available through one automotive-type shift lever. Ratios are 1:1; 2:1; 3:1 and 4:1. Gears and shafts are of alloy steel, heat-treated. Gears are lapped. Revolving shafts are mounted on anti-friction bearings and case is oil sealed.

### Gapless Piston Ring

*The Auto-Diesel Piston Ring Co., 3272 Superior Ave., Cleveland 14, Ohio.*

Ring consists of two identical parts that interlock when assembled and form a ring without a gap. The Auto Diesel Helicam gapless piston ring is adapted for carrying oil within itself, and it can also be used as an oil ring while retaining its expanding features. The illustration shows the ring semi assembled.



### Washer-Type Rivnut

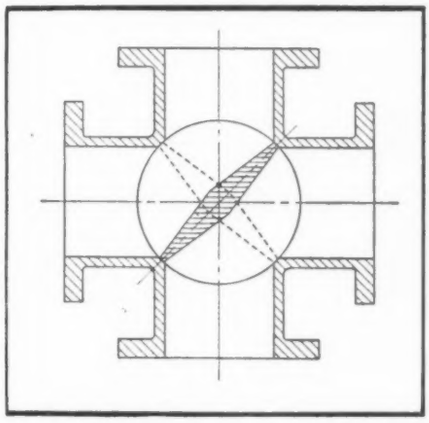
*The B. F. Goodrich Co., Akron, Ohio.*

A washer head Rivnut, a one-piece internally threaded and counterbored tubular cadmium plated steel rivet that can be upset or headed from one side. At present furnished only in No. 6-32 thread for fastening 1/4 in. plywood to 1/16 in. steel sections. It is claimed it will not vibrate loose; is easier to install than either wood or self-tapping screws; is useful as a nut plate for fastening interior trims; fits flush with plywood and will not pull through plywood.

### Transfer Valve

*R-S Products Corp., Philadelphia 44, Pa.*

A single vane, quick-operating control valve, designed to transfer chemicals, oil, paper pulp, sewage, water and other materials from one line to another at 125 lb. per sq. in. It can be manually or automatically

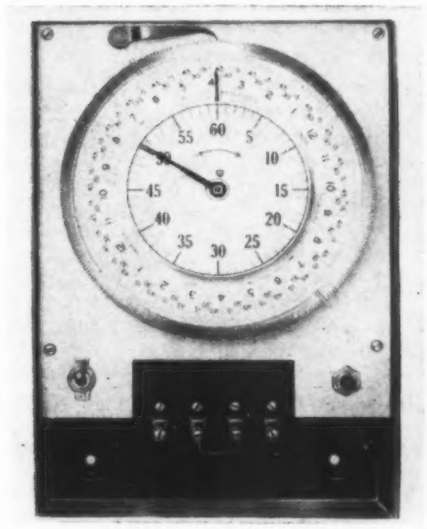


operated. Equipped with adjustable stop screws and indicator to determine vane position. Can be fabricated from all types of metals in sizes from 4 to 72 inches.

### Electric Time Switch

*Zenith Electric Co., 152 W. Walton St., Chicago 10, Ill.*

Program Time Switch, Type PR-24, operates automatically to periods of five minutes throughout twenty-four hours, or any part




thereof. It repeats daily, requiring no attention other than the setting. The unit is inclosed in a steel case 8 x 12 x 4 inches.

# NEW BOOKS

## Electronic Equipment and Accessories

R. C. Walker, 393 pages, 343 illustrations, 15 chapters 8¾x6 in., red clothboard covers. Published by Chemical Publishing Co., Inc., 26 Court Street, Brooklyn 2, N. Y. Price $6.

For practical engineers, mechanics, students, and others who have rudimentary knowledge of electricity and magnetism and wish to learn to use electronic equipment and accessories.

Typical chapters include: Fudamentals of thermionic valves, methods of amplification, light sensitive devices and their use, relays, small switchgear, and miscellaneous accessories for use in electronic circuits.

## Porcelain Enameling Reference Manual

*Prepared and published by the Pemco Corp., Baltimore, Md. 12 in. x 12 in. black leather 3-ring loose-leaf cover. Price $5.00.*

The purpose of the manual is to correlate the essential knowledge of porcelain enameling plant control in relation to the importance of cost reduction and to bring about the correction of enameling shop problems and simplification of purchasing. The manual contains nine main index sections comprising enameling specifications and Porcelain Enamel Institute booklets on various enameling tests. Seven complete sets of plant and laboratory control and layout charts are likewise included. Additional material will be supplied for inclusion by the Pemco Corp. at various times in order to keep the manual up to date.

## Marine Engineers' Handbook

J. M. Labberton and Lionel S. Marks. 1450 pages, 4½ in. x 7 in., maroon semi-flexible covers. Published by McGraw-Hill Book Co., Inc., New York, N. Y. Price $7.50.

A new edition of Sterling's Marine Engineers' Handbook, brought up to date and almost completely rewritten, containing information for the designer of marine equipment. Included are engineering fundamentals, charts, tables, formulas, descriptions, design data, methods and construction details of marine power generation, hulls and propulsion, heating, ventilating, pumps, and electrical engineering.

## Electrons In Action

James Stokley, 320 pages, 5½x8¼ in., black clothboard covers. Published by McGraw-Hill Book Co., 330 W. 42nd St., New York 18, N. Y. Price $3.

Clearly written, non-technical, interpretative story of the electron, telling what electrons are, where they come from, and how they are used. Diagrams, similes, and examples are used generously.

The seventeen chapters include an explanation and discussion of frequency modulation, television, cosmic electronics, radar, loran, and the atomic bomb. Other chapters deal with the part electronics plays in industry, electronic recording of sound, the computer, the X rays, the betatron, the electron microscope, and the various applications of electronics to medical instruments, such as the metal locator, the inductotherm, and the electroencephalogram.

## A Treatise on Milling and Milling Machines

*Prepared and published by the Cincinnati Milling Machine Co., Cincinnati 9, Ohio. 6 in. x 9 in. brown paperboard covers, 183 pages. Volume I of a proposed series. Price $1.00.*

A general text on the construction and operation of milling machines as well as the cutting tools used for performing milling operations. Typical milling examples, illustrating equipment installed in manufacturing plants, are used to describe proper fixture and work-chucking devices, and the most economical cycles of operation. Included are sections on milling, cutting materials, cutter body materials, and detailed information on the sharpening and care of milling cutters.

## High Vacuum Technique

J. Yarwood 140 pages, 6x9¼ in., black clothboard covers. Published by John Wiley & Sons, 440 4th Ave., New York 16, N. Y. Price $2.75.

This is the second edition of the book, which presents the theory, practice and industrial application of high vacuum techniques. It describes the production and measurement of high vacua and explains the physical bases of the methods adopted.

The revised edition includes new sections on the performance of vacuum pumps, the construction of vacuum systems, extra methods of measuring low pressures and pumping speed. Twenty-six new diagrams appear in this edition.

## Electron Optics and the Electron Microscope

V. K. Zworykin, G. A. Morton, E. G. Ramberg, J. Hillier and A. W. Vance. 766 pages, 5½x8½ in., black clothboard covers. Published by John Wiley & Sons, 440 4th Ave., New York 16, N. Y. Price $10.

Electron microscopy has developed, within the past ten years, from a subject of purely academic interest into one of great practical importance. Recognizing this, the authors wrote this book to meet the need for a comprehensive discussion of the modern electron microscope.

The book is divided into two parts: Part I includes a description of the various types of microscopes, a non-mathematical discussion of electron optical theories on which the electron microscope is based, and a practical guide for the effective operation of the microscope. Part II presents a survey of theoretical electron optics, employing mathematics in a methodical development of the subject.

## Elements of Ammunition

Theodore C. Ohart. 412 pages, 6x9¼ in., red clothboard covers. Published by John Wiley & Sons, 440 4th Ave., New York 16, N. Y. Price $6.

The author, a major in the Army Ordnance Department, wrote this book to train inexperienced personnel in ammunition design. The book describes the design, construction and uses of all types of ammunition, including the main categories of small arms artillery, aircraft and rocket ammunition. Such items as the bazooka, beach barrage rockets, long range artillery, block busters, fire bombs, pistol and rifle ammunition, chemical warfare ammunition, photo-flash bombs and the newer explosives are fully discussed.

## Testing Plastics Parts

*Prepared and published by the Society of the Plastics Industry, 295 Madison Ave., New York, N. Y. Fourth chapter of the technical handbook being developed by the Engineering and Technical Committee of S.P.I. Price $1.00.*

This chapter relates primarily to tests which are given various finished articles to ascertain their ability to stand up under consumer usage. Among the tests described in the chapter are: Impact tests to determine the strength and resistance to shocks of various products; moisture resistance tests; means for ascertaining dimensional stability; heat resistance; crushing tests and others.

## Applied Energy Conversion

Bernhardt, G. A. Skrotzki and William A. Vopat, 509 pages, 5¾x8½ in. Clothboard covers. Published by McGraw-Hill Book Co., 330 West 42nd St., New York 18, N. Y. Price $5.

A textbook in power plant engineering that is intended for a background course in the power field. The text is divided into what may briefly be designated as equipment and economic sections. The first part explains the functions and operating principles of the major equipment used commercially in the conversion of energy, with a concise consideration of its performance characteristics. The evolution of an operating central station from a combination of power plant equipment, Diesel and gas-engine plants, and special developments in steam and power are treated in subsequent chapters.

Basic concepts of economics applicable to power are treated in the second section, which comprises about the last third of the text. Load curves, capacity scheduling, selection of unit sizes, increment fuel cost, energy rates and rate design are among the items covered.

# Nomograms of Chords of Holes in Bolt Circles

LOUIS DODGE

THE ACCOMPANYING nomographic charts are used to determine the chords of holes in bolt circles when designing pipe flanges, shaft couplings, and similar work entailing the circular spacing of holes. The charts give a graphical solution to the relationship.

$$C = 2\ R \sin \frac{180^\circ}{N}$$ where,

$N$ = the number of holes in the bolt circle

$R$ = the radius of the bolt circle in inches

$C$ = the chordal distance in inches.

Chart I is for bolt circles from 1 to 7 in. radius and Chart II is for radii from 6 to 20 in.

An example is solved on Chart II (see dashed lines).

(*Continued on next page*)

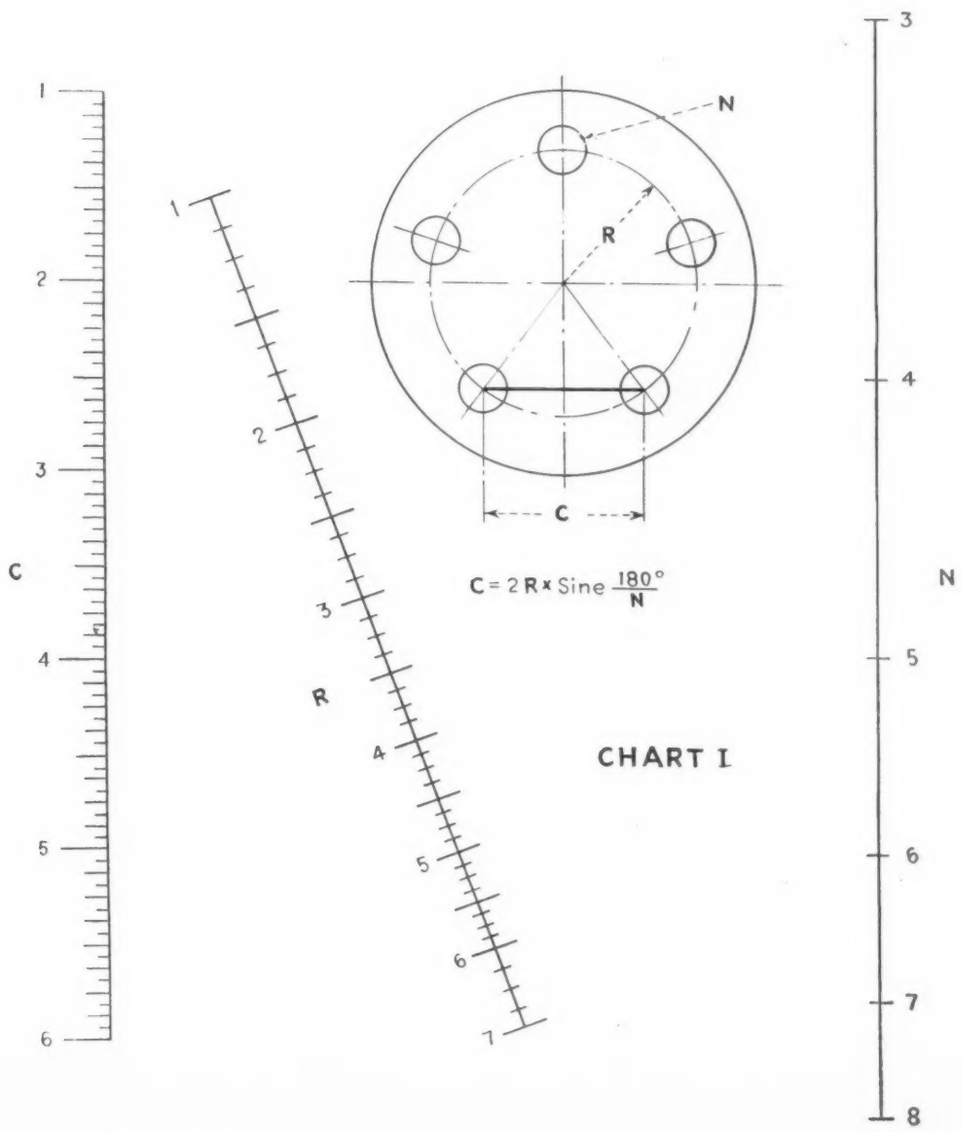
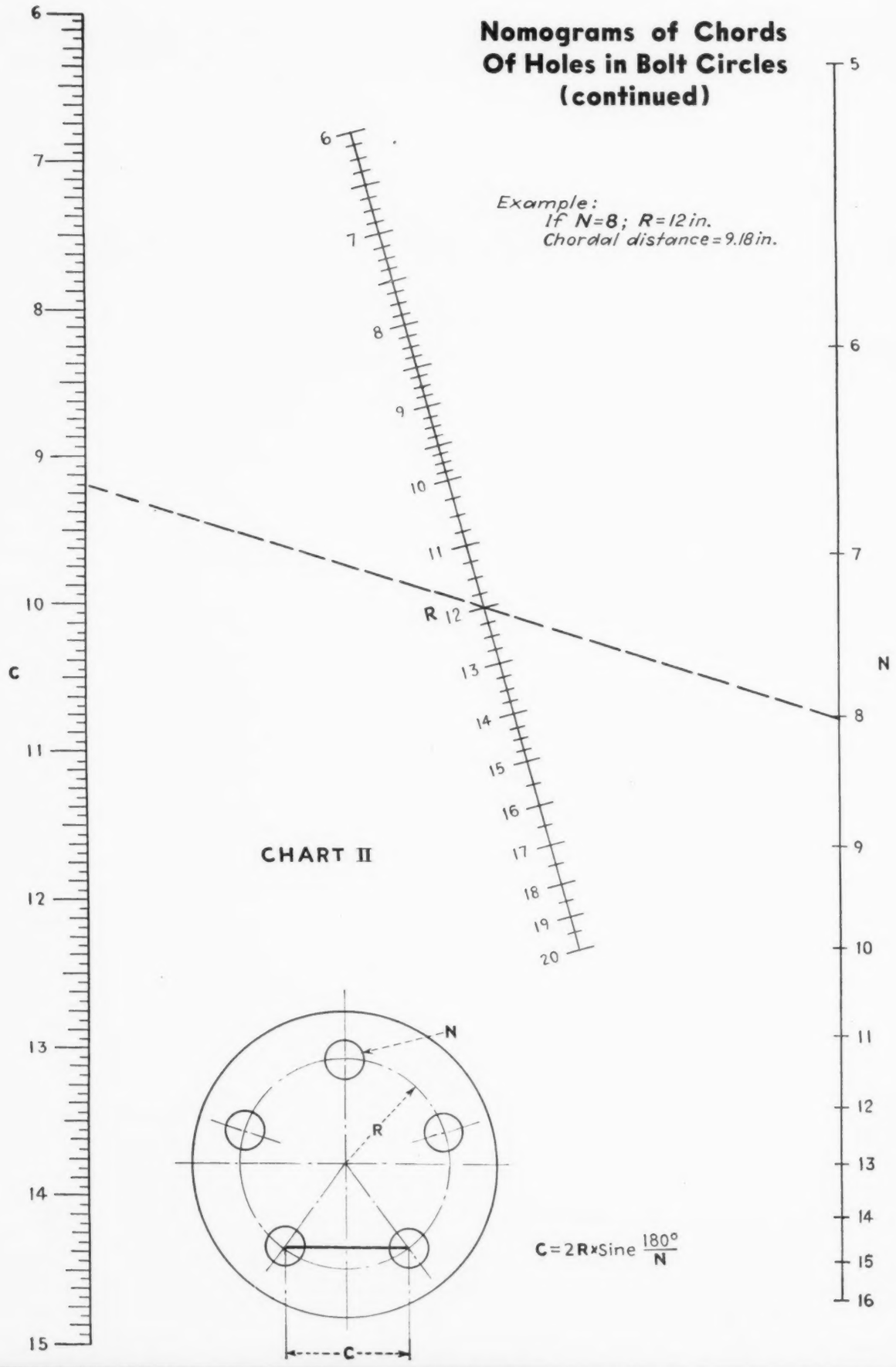



CHART I

# Nomograms of Chords Of Holes in Bolt Circles (continued)




**PRODUCT ENGINEERING — REFERENCE BOOK SHEET**